## Deliverable C2.1, Part 2: Energy sector models

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# Documentation of Methods and Models for Climate Mitigation Mid-century Strategy Scenario Analysis

## Final report

**LIFE ClimatePath2050 (LIFE16 GIC/SI/000043)**

**Projekt LIFE ClimatePath2050 (LIFE16 GIC/SI/000043) je sofinanciran iz sredstev LIFE, finančnega inštrumenta Evropske unije za Okolje in podnebne spremembe na prednostnem področju Podnebno upravljanje in informacije in iz sredstev Ministrstva za okolje in prostor RS, Sklada za podnebne spremembe.**
With the contribution of the LIFE Programme of the European Union and the Ministry of the Environment and Spatial Planning, Republic of Slovenia, the Climate Change Fund.

Deliverable C2.1, Part 2: Energy sector models was prepared within the project LIFE ClimatePath2050 “The Slovenian Path Towards the Mid-Century Climate Target” (LIFE Podnebna pot 2050, Slovenska podnebna pot do sredine stoletja, LIFE16 GIC/SI/000043). The project is being carried out by a consortium led by the Jožef Stefan Institute (JSI), with partners: ELEK, the Building and Civil Engineering Institute ZRMK (GI ZRMK), the Institute for Economic Research (IER), the Agricultural Institute of Slovenia (AIS), PNZ and Slovenian Forestry Institute (SFI).

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### REPORT TITLE/NASLOV POROČILA:

**Deliverable C2.1: Documentation of Methods and Models for Climate Mitigation Mid-century Strategy Scenario Analysis**, Part 2: Energy sector models, final report

**Poročilo projekta št. C2.1, Metode in modeli za analizo strateških scenarijev blaženja podnebnih sprememb do sredine stoletja**, Drugi del: Sektorski energetski modeli, končno poročilo

# Table of Contents

# Introduction

In the scope of LIFE ClimatePath2050[1] the **Deliverable C2.1: Documentation of Methods and Models for Climate Mitigation Mid-century Strategy Scenario Analysis**, Part 2: Energy sector models was prepared. The document presents the information on the models developed or updated in the scope of the project along with some basic results of models use.

The composite deliverable C2.1: Documentation of Methods and Models for Climate Mitigation Mid-century Strategy Scenario Analysis consists of several parts, namely:

- **Part 1: Summary report on methods and models for scenario analysis**, condense summary report on methods and models for scenario analysis;
- **Part 2: Energy sector models**, includes the detailed information on sectoral models used for climate mitigation scenario analysis, the report enlightens general approach and presents final energy demand and supply models including households, services and agriculture energy use, energy use in transport and industry, models for district heating expansion analysis and CHP cross sectorial impact, distributed electricity production assessment and optimisation of power sector operation;
- **Part 3: LULUCF model**, includes the detailed information on Carbon Budget Model (CBM-CFS3) that is used for simulating the dynamics of forest carbon pools, considering various assumptions such as the type of forest management, land use changes, the occurrence of natural disturbances and timber harvesting;
- **Part 4: Other IPCC sectors agriculture, sector process emissions, IPCC sector waste**, includes information on the models used for assessing agriculture sector, process emissions and waste in accordance with IPCC;
- **Part 5: Macroeconomic model**, includes the detailed information on the newly developed multi-sectoral Computable General Equilibrium model (CGE) of the Slovenian economy (GreenMod Slovenia) that was developed and used specifically for the analysis of energy and environmental issues, considering the quantitative results of the energy sector models.

The deliverable **Part 2: Energy sector models**, includes the detailed information on sectoral models used for climate mitigation scenario analysis, the report enlightens general approach and presents energy final energy demand and supply models and highlights each model results. The models were used to assess the Climate Mitigation Mid-century Strategy scenarios.

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[1] LIFE ClimatePath2050 (Slovenian Path Towards the Mid-Century Climate Target)

Projekt LIFE ClimatePath2050 (LIFE16 GIC/SI/000043) je sofinanciran iz sredstev LIFE, finančnega inštrumenta Evropske unije za Okolje in podnebne spremembe na prednostnem področju Podnebno upravljanje in informacije in iz sredstev Ministrstva za okolje in prostor RS, Sklada za podnebne spremembe.
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# REES-SLO model

## 1.1 Purpose of the model

In the following chapter the model of the national energy system REES-SLO, which was designed and realized in the MESAP environment in the scope of LIFE ClimatePath 2050 project is presented. The connections with other models and sub-models are highlighted. REES-SLO model represents a central tool for calculating long-term energy balances and enables scenario-based policy impact assessment.

With the aim to describe technical, economic and environmental characteristics of the Slovenian energy system, new Reference Energy and Environmental System model (REES-SLO) has been developed. The REES-SLO model was used as a decision support tool for national strategic energy planning. Since the modelling results have significant influences on decisions of energy systems planning and emission management, our imperative was to develop an advanced energy systems model which can effectively handle peculiarities of the small energy systems and provide sound decision supports. During the development process we were fully aware that the national energy systems are extremely difficult to model since they are depending on many very complex input parameters. Value added of the new REES-SLO is very strong environment component which was added to the classical Reference Energy System concept and clear focus on interactive and dynamic characteristics of relatively small Slovenian energy systems with the aim to objectively tackle decision problems, such as future energy infrastructure development, power generation expansion and greenhouse gases (GHG) emission reduction.

## 1.2 Integrated model system REES-SLO

The central tool to calculate energy balances, emissions and costs of energy use and supply in Slovenia is a reference energy-ecological model called REES-SLO, created in the MESAP environment in the form of a linear network model of processes and interconnections, which enables consistent modelling of energy consumption based on energy service needs and calculations of sectoral energy, economic, environmental and other impacts. A reference model of an energy system is essentially a set of programmes and tools that mathematically describe an individual subsystem in the interdependence of all the variables that affect such a subsystem, and then integrate those subsystems into an appropriate whole that represents the real energy system.

MESAP software allowed us to graphically show and implement REES-SLO model with all its characteristics. Every sector is a standalone process, each having its own input and output parameters and equations that describe the connections between them. As a result, our MESAP model then summarize emissions released and energy produced and used in every sector to calculate energy consumption balances (useful, final, secondary, primary energy, namely for the entire energy system and by subsectors, energy sources, technologies) and emissions of harmful substances (SO2, NOx, CH4, N2O, dust particles) from energy conversions (by sectors, energy sources, technologies, by conversion levels and total).

The REES-SLO is a set of programmes and tools where each subsystem has been described mathematically in correlation with parameters that influence such a subsystem and

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interconnected to represent the national energy system. Modern energy system models, use an integrated approach, derived from the theoretical background of Integrated Resource Planning, combining the characteristics of specific and general models so that sectoral energy, economic and environmental impacts can be assessed. A schematic illustration of the overall concept and interconnections of the individual models is presented in the figure below.

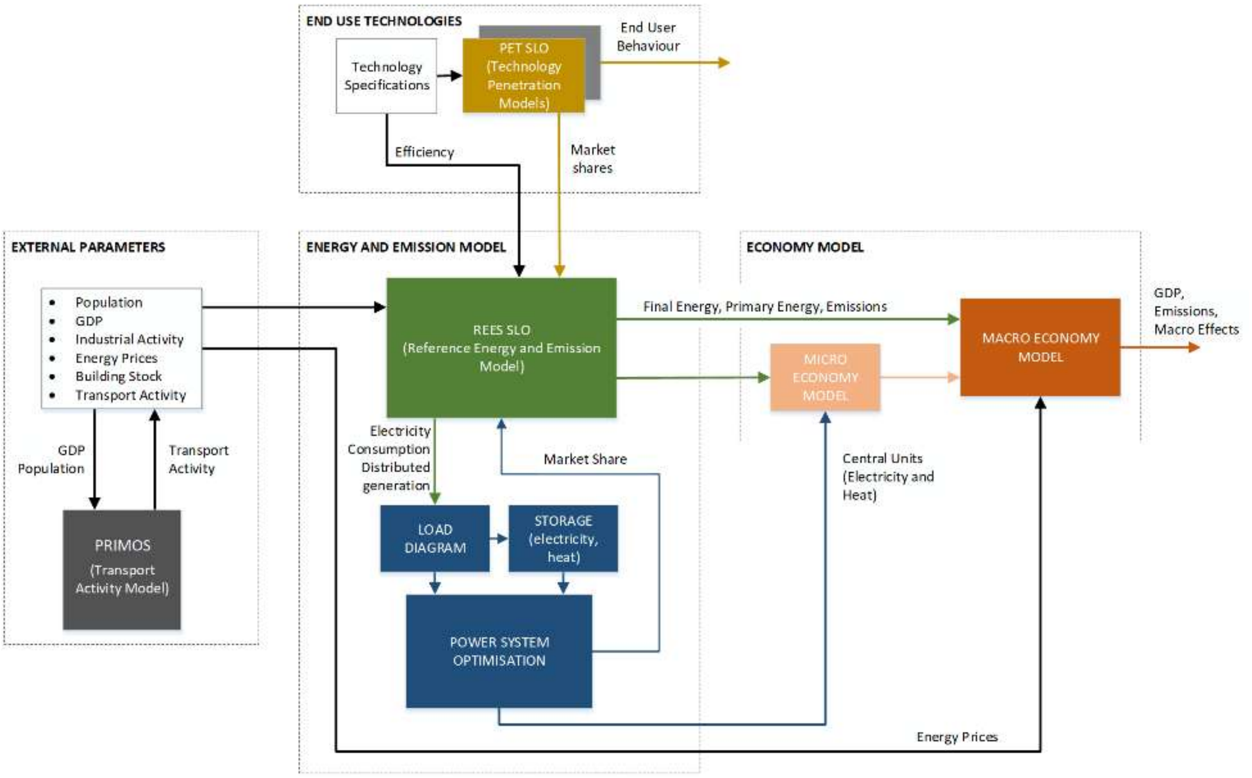

**Figure 1: REES-SLO model interconnections**

A core computation model is a Modular Energy System and Planning (MESAP) tool. The MESAP standard software is a platform for building customer specific strategic information systems. The core of MESAP is a powerful database that gathers all the information in a central data pool. The simulation model of MESAP environment is called PlaNet and consists of two independent modules: a module which balances flows of energy (end-use and supply) and the module for calculating macroeconomic costs linked to selected commodity flows. MESAP is a linear accounting model with flexible data structure and it can be adapted to the level of aggregation and accommodated to any reasonable level of detail. Scenario-based planning was integrated into the MESAP environment, allowing integration of past, present and planned (calculated) data in a comprehensive overall system. MESAP software can be used in national or regional energy system modelling and it has no limitations regarding the scenario timeframe or time-step. Combined with its open structure, this makes MESAP a very suitable modelling tool for relatively small energy systems where many peculiarities have to be considered. During the redevelopment of the REES-SLO model trade-off between the simulation and optimisation approach has been done, again favouring presentation of relations between controls and their effects rather than the elusive optimality of results which can be misleading for small energy systems. Nevertheless, several other tools from the MESAP toolbox, including optimisation modules, can be applied to the developed model.

Within the model the most important driving forces (demand determinants) such as: value added and volume of physical production in economic activities, transport output/volume, building stock structure, space heat demand distribution, number of households, dwelling surface, penetration of new and energy efficient appliances in households and other details like superficies of schools or number of beds in hospitals have been analysed. Special attention was given to the aggregation of data in accordance with the statistical standards for data classification. Economic activities have been disaggregated by branches, manufacturing industry and service sectors are further disaggregated on the sub-branch level.

The model consists of sub-models for the following sectors: energy use in industry, households, service sector, transport, local energy supply and central energy supply.

MESAP supports a technology-oriented modelling approach where several competitive technologies that supply energy services are represented by parallel processes. The volume of a service supplied by a technology (e. g. heat) is defined by market shares that split the service demand between processes (technologies) that can supply selected service. Open structure approach enables the modelling of new, low carbon technologies and different intensity options of the transition to a low carbon society. Also, parallel competitive technologies have been included in the model as shown in Figure 2.

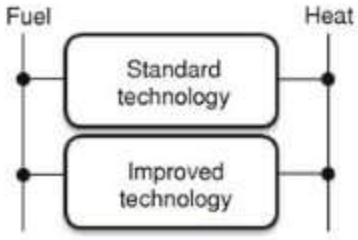

**Figure 2: Parallel technologies modelling approach**

The segmentation within the model between standard and improved technologies have been made on technical, economic and environmental characteristics of calculated energy flows, costs and emissions for both standard and improved parallel technologies. Parallel modelling of technologies enabled accurate estimation of induced costs, environmental impacts and increased transparency, consistency and precision of the model.

Modern energy system models, use an integrated approach, derived from the theoretical background of Integrated Resource Planning, combining the characteristics of specific and general models so that sectoral energy, economic and environmental impacts can be assessed. A schematic illustration of the overall concept and interconnections of the individual models is presented in the figure below.

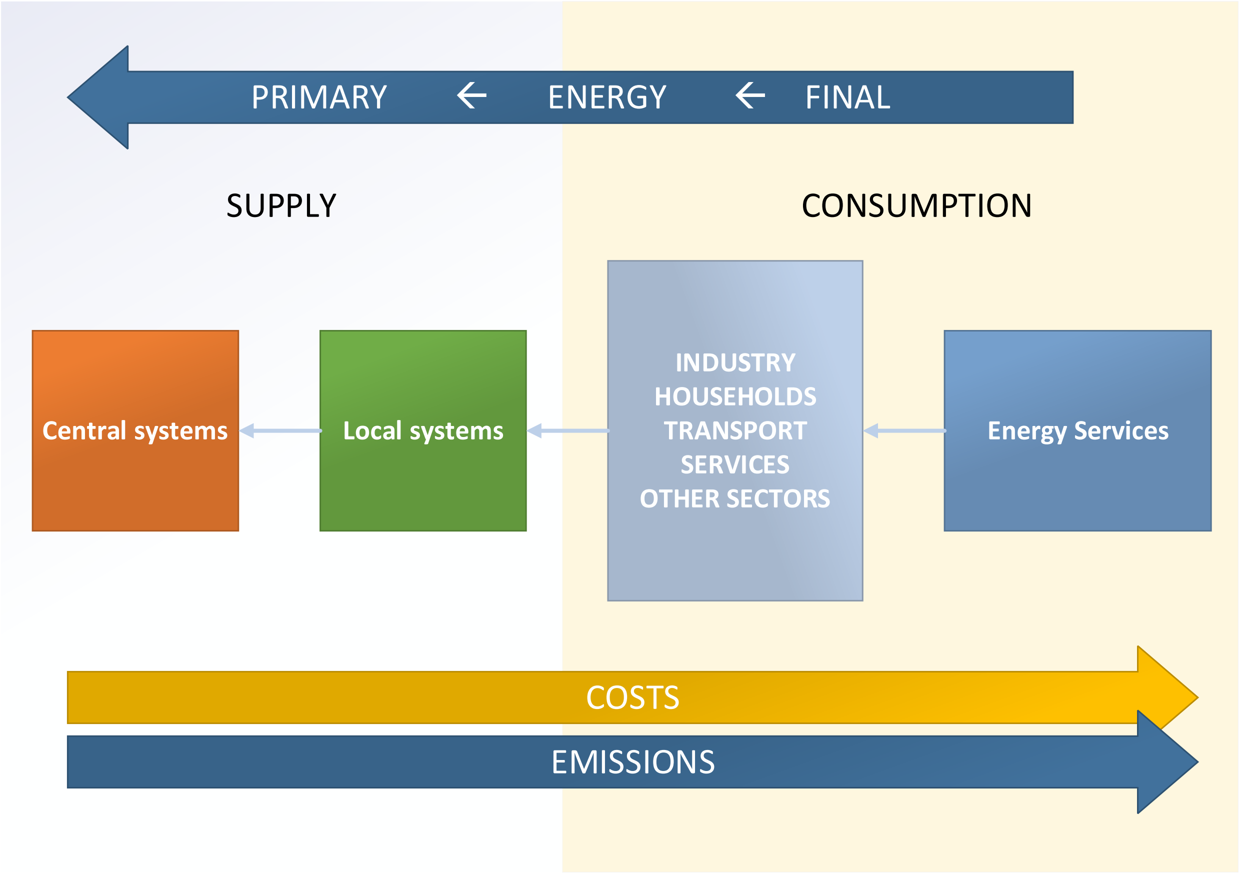

**Figure 3: Structure of REES-SLO model**

Process flow relations are defined by a set of linear equations (transformation, exogenous, commodity consumption, commodity production, and allocation equations), freely defined for each process. Non-linear problems like losses in the electricity distribution network are linearized, i.e. described with a set of linear functions without any trigonometric or nonlinear terms. The reference energy system in the MESAP environment is a bipartite graph, consisting of three basic structures: process, commodities and flows.

Within the first step material commodity flows are specified and corresponding costs are calculated. Through determined/projected intensity, such as electricity use per person, the need for energy supply in distribution network is calculated and the end-use consumption is modelled. In the case where several processes that produce commodity flows are applied, a market share of individual process is determined. The input commodity flow is determined using the efficiency of each process. The MESAP tool enables the simulation of quantities and costs of primary and end-use energy flows through efficiencies, market shares and intensities. The process performs the function of converting one or more of the commodities into new commodities through flows. In REES-SLO the basic modelling principle is the differentiation of fuels and processes by characteristics, regarding efficiencies, costs or environmental parameters.

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## 1.1 Model Inputs

Within the REES-SLO the most important parameters that have significant influence on the future energy consumption were recognised, namely:

- physical product in industries and other economic activities for each addressed industry branch;
- dwelling surface of buildings and employment in the service sector,
- household size and structure of building stock, number of households, and
- transport output/volume, structure of transport.

Also, different external parameters that have significant influence on the REES-SLO model were recognised and applied to scenarios. The most important external parameters that have significant influence on the REES-SLO model are international and regional fuel prices, projected economic growth in the Slovenia and European Union, availability, market penetration and dynamics of market shares for energy efficient technologies. In our case the time horizon was the period from 2020 up to 2050 with 2017 as the base year.

Energy consumption and supply data for the base year have been obtained from the Statistical Office of the Republic of Slovenia and from other relevant sources, while hourly production and load data for the Slovenian power system have been provided by the Slovenian Transmission System Operator (ELES). Within the Power sector optimisation module (separate model connected to the REES-SLO, described in section 2.7 Optimisation of power sector operation (central system) for expansion planning) hourly time steps are considered.

For the reporting purposes it has been decided that the data should be normalised on the yearly basis for each 5 years interval (2020, 2025, 2030, 2035, 2040, 2045 and 2050). Load curves for the hourly district heating demand were obtained from local district heating system operators. Heat and process steam demand in industry were treated separately, through energy consumption of industrial sector and have been disaggregated by sub-branches.

Entire REES-SLO model was built having in mind the interplay between sectors in smart energy systems of the future. For example, the development of smart grids is assessed directly as the precondition for the wider deployment of distributed electricity generation units (renewable energy sources and high efficiency combined heat and power – CHP production units) and indirectly through the overall increase of energy efficiency (consumer awareness).

## 1.2 Energy balance and emission calculation module

For the energy balance and emission calculation a separate module has been developed in MESAP environment. The resulting energy flows from each of the final energy sectors along with the energy required at the supply side are fed into the Balance module which in essence presents the scenario assessment tool. In this module the reports are generated in line with the

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statistics and reporting requirements and automatized graphical representation of the results is prepared. The Balance module of the model is divided into 12 process: transport, households, tertiary sector (services), central energy supply, agriculture, industry, construction, local energy supply, energy use and losses, mining, energy sector, and fugitive emissions.

For each the energy, emission and cost flows are determined and connected to the certain addressed scenario. In that manner, scenario-based analysis is enabled.

| | | | | | WAM-H | WAM-H | WAM-H | WAM-H | WAM-H | WAM-H | WAM-H | WAM-H |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| | | | | | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| | | | GREENHOUSE GAS SOURCE AND SINK CATEGORIES | | | | | | | | | |
| | | | 1. Energy | [kt CO2 ekv] | 14,359.2 | 13,383.2 | 12,631.1 | 10,125.6 | 6,472.0 | 4,101.8 | 2,224.0 | 297.8 |
| | | | A. Fuel Combustion (Sectoral Appro | [kt CO2 ekv] | 13,952.4 | 12,995.4 | 12,294.1 | 9,844.2 | 6,149.5 | 5,821.7 | 1,922.8 | 241.4 |
| | | 1.A.1. | 1. Energy Industries | [kt CO2 ekv] | 4,870.9 | 4,440.9 | 4,191.4 | 2,949.0 | 838.1 | 683.4 | 522.0 | 28.0 |
| | | 1.A.2. | 2. Manufacturing Industries and Co | [kt CO2 ekv] | 1,692.8 | 1,627.3 | 1,318.6 | 1,278.5 | 1,165.6 | 926.7 | 537.3 | 74.9 |
| | | 1.A.3. | 3. Transport | [kt CO2 ekv] | 5,908.0 | 5,699.8 | 5,623.2 | 4,963.6 | 3,678.3 | 1,898.7 | 898.8 | 45.5 |
| | | 1.A.4. | 4. Other Sectors | [kt CO2 ekv] | 1,476.5 | 1,223.5 | 916.8 | 651.1 | 463.5 | 308.8 | 160.6 | 88.9 |
| | | 1.A.4.a | a. Commercial/Institutional | [kt CO2 ekv] | 378.3 | 252.2 | 166.2 | 109.3 | 70.7 | 42.6 | 19.2 | 9.9 |
| | | 1.A.4.b | b. Residential | [kt CO2 ekv] | 850.6 | 733.3 | 526.6 | 343.4 | 218.0 | 139.1 | 87.5 | 64.4 |
| | | 1.A.4.c | c. Agriculture/Forestry/Fisheries | [kt CO2 ekv] | 247.7 | 238.0 | 224.0 | 198.4 | 174.8 | 127.1 | 53.9 | 14.5 |
| | | 1.A.5. | 5. Other | [kt CO2 ekv] | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| | | | B. Fugitive Emissions from Fuels | [kt CO2 ekv] | 408.9 | 387.8 | 377.0 | 281.4 | 322.5 | 280.1 | 301.3 | 56.4 |
| UbezneEmisije_UG_CO2 | UbezneEmisije_UG_CH4 | | 1. Solid Fuels | [kt CO2 ekv] | 359.7 | 341.0 | 324.4 | 228.5 | 267.5 | 224.6 | 245.2 | 0.0 |
| UbezneEmisije_UNP | UbezneEmisije_Plin_CO2 | UbezneEmisije_Plin_CH4 | 2. Oil and Natural Gas | [kt CO2 ekv] | 47.18 | 46.73 | 52.64 | 52.88 | 54.97 | 55.51 | 56.13 | 56.43 |
| | | | C. CO2 transport and storage | [kt CO2 ekv] | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

**Figure 4:Example of results template preparation**

Required inputs for **transport** sector process in MESAP model are end use of energy and emission factors for every combination of technology and fuel available and predicted in our scenarios, and for every year in before mentioned time period. End use of energy is modelled and calculated in sectoral models. For every combination of technology and fuel present in our transport sector MESAP model, emissions are calculated with simple equation, where we multiply end use of energy with emission factor for each of those combinations.

Input data for **household** sector process, **tertiary** sector process, **agriculture** sector process, **construction** sector process, **mining** sector process and **energy** sector process are same as for transport sector process. The example of the MESAP environment and the development screenshot for the transport sector is presented in the figure below.

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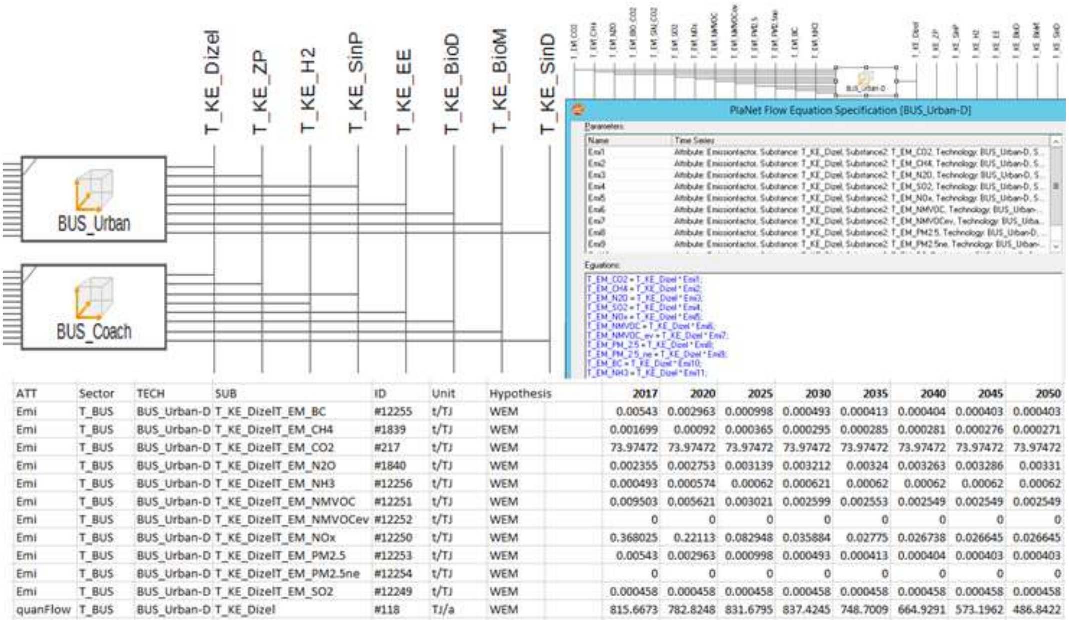

| Name | Time Series |
|---|---|
| Emi1 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_CO2, Technology: BUS_Urban-D, S... |
| Emi2 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_CH4, Technology: BUS_Urban-D, S... |
| Emi3 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_N2O, Technology: BUS_Urban-D, S... |
| Emi4 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_SO2, Technology: BUS_Urban-D, S... |
| Emi5 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_NOx, Technology: BUS_Urban-D, S... |
| Emi6 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_NMVOC, Technology: BUS_Urban-... |
| Emi7 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_NMVOCev, Technology: BUS_Urba... |
| Emi8 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_PM2.5, Technology: BUS_Urban-D, ... |
| Emi9 | Attribute: Emissionfactor, Substance: T_KE_Dizel, Substance2: T_EM_PM2.5ne, Technology: BUS_Urban-... |

```
T_EM_CO2 = T_KE_Dizel * Emi1;
T_EM_CH4 = T_KE_Dizel * Emi2;
T_EM_N2O = T_KE_Dizel * Emi3;
T_EM_SO2 = T_KE_Dizel * Emi4;
T_EM_NOx = T_KE_Dizel * Emi5;
T_EM_NMVOC = T_KE_Dizel * Emi6;
T_EM_NMVOC_ev = T_KE_Dizel * Emi7;
T_EM_PM_2.5 = T_KE_Dizel * Emi8;
T_EM_PM_2.5_ne = T_KE_Dizel * Emi8;
T_EM_BC = T_KE_Dizel * Emi10;
T_EM_NH3 = T_KE_Dizel * Emi11;
```

| ATT | Sector | TECH | SUB | ID | Unit | Hypothesis | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_BC | #12255 | t/TJ | WEM | 0.00543 | 0.002963 | 0.000998 | 0.000493 | 0.000413 | 0.000404 | 0.000403 | 0.000403 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_CH4 | #1839 | t/TJ | WEM | 0.001699 | 0.00092 | 0.000365 | 0.000295 | 0.000285 | 0.000281 | 0.000276 | 0.000271 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_CO2 | #217 | t/TJ | WEM | 73.97472 | 73.97472 | 73.97472 | 73.97472 | 73.97472 | 73.97472 | 73.97472 | 73.97472 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_N2O | #1840 | t/TJ | WEM | 0.002355 | 0.002753 | 0.003139 | 0.003212 | 0.00324 | 0.003263 | 0.003286 | 0.00331 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_NH3 | #12256 | t/TJ | WEM | 0.000493 | 0.000574 | 0.00062 | 0.000621 | 0.00062 | 0.00062 | 0.00062 | 0.00062 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_NMVOC | #12251 | t/TJ | WEM | 0.009503 | 0.005621 | 0.003021 | 0.002599 | 0.002553 | 0.002549 | 0.002549 | 0.002549 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_NMVOCev | #12252 | t/TJ | WEM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_NOx | #12250 | t/TJ | WEM | 0.368025 | 0.22113 | 0.082948 | 0.035884 | 0.02775 | 0.026738 | 0.026645 | 0.026645 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_PM2.5 | #12253 | t/TJ | WEM | 0.00543 | 0.002963 | 0.000998 | 0.000493 | 0.000413 | 0.000404 | 0.000403 | 0.000403 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_PM2.5ne | #12254 | t/TJ | WEM | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Emi | T_BUS | BUS_Urban-D | T_KE_DizelT_EM_SO2 | #12249 | t/TJ | WEM | 0.000458 | 0.000458 | 0.000458 | 0.000458 | 0.000458 | 0.000458 | 0.000458 | 0.000458 |
| quanFlow | T_BUS | BUS_Urban-D | T_KE_Dizel | #118 | TJ/a | WEM | 815.6673 | 782.8248 | 831.6795 | 837.4245 | 748.7009 | 664.9291 | 573.1962 | 486.8422 |

**Figure 5: Example of equations and data requested in MESAP model for urban buses running on diesel category**

Calculations in **central energy supply** (CES) processes are a bit different. Central energy supply in REES-SLO model is divided between power generating units/plants. For those plants we know their power and their present working hours, as well as their present electricity and heat production. Depending on the calculated electricity demand the quantities of fuel used for production and emissions produced from energy conversion are determined. Different addressed scenarios have different electricity and heat production according to demand, production technologies portfolio and alternate working hours. Some of those plants use more than one fuel to produce electricity and heat. Therefore, we use a ratio parameter to determine what amount of production came from which fuel, as shown by the following example equation:

*CES_EndUseOfEnergy_Lignite = ElectricityProduced * **LigniteRatio** / TransformationEfficiencyLignite.*

Similar approach is used for the emission calculation since emissions are directly linked to the use of fuels. Local energy supply is addressed in the same way. Power and working hours for bigger plants, that we can alternate between scenarios. For other units, we can't change their production, we can only change the share of each technology, and by that practically alternate the quantity of those units.

**Energy use loses** (EUL) process data values estimated/defined for different technologies and calculated in the balance module in accordance with the production and demand flows.

Emissions in **fugitive emissions** (FE) process are calculated by taking sum of end use of energy (EUE) in every sector or process that is using a fuel which emits fugitive emissions and multiply it with the »fugitive« emission factor of that fuel as shown by the equation bellow.

*FE_Gas_CO2_Distribution = (Transport_EUE_NaturalGas + Households_EUE_NaturalGas + Tertiary_EUE_NaturalGas+....) * **FugitiveCO2DistributionEmissionFactor***

## 1.3 Analysis steps

The use of reference energy models in energy is already a well-established practice and methodology of comprehensive planning "live" at the Jožef Stefan Institute's Energy Efficiency Centre for several years. The REES-SLO model was planned according to the methodology of integrated energy planning. In addition to the REES-SLO model, other models and sub-models are connected to the REES-SLO model in various way and used in the analysis and impact assessment of energy policy measures. The overall analysis takes place in four stages, namely:

1. the model for market penetration assessments of energy-efficient technologies (**PET SLO**) calculates the market shares of individual energy efficiency technologies by end-users in response to changed price signals, financial incentives and information campaigns. Technologies that are enforced as a result of regulations on minimum energy performance requirements (buildings, appliances, products) are modelled separately. Energy efficiency measures in energy-intensive activities are also modelled separately. Estimates of the market shares of individual technologies and their costs are input for the basic model of the REES-SLO reference energy system.
2. REES-SLO calculates the prospective energy end-use balances and estimates local electricity production based on the shares of different technologies in the end-use structure and connections with influential parameters (levels of economic activity by industry, number of households, etc.). The final use of electricity, broken down by sector and by purpose, and production in local supply systems (in industrial, distribution and private units) is transferred to the processing of the programme for the analysis of the form of the demand chart.
3. Using the Power sector optimisation model, the total electricity production and consumption, the system price and the quantity that each producer will have to provide are calculated. The calculation is based on optimisation of the offers of all producers in relation to prices on international markets, considering the technical constraints of individual installations and the reliability objectives for the system.
4. The shares of electricity generation in each unit calculated in step 3 and the associated costs are transferred to the REES-SLO model. The model calculates other balances for the entire planning period: primary and secondary energy, emission balances and corresponding emissions (CO2, CH4, N2O, SO2 and NOX) and total costs.
5. Energy, emission and cost components and flows are fed to the macroeconomy model as inputs for the macroeconomic assessment. Impacts on national economy aggregates of different scenarios are addressed.

The logical process and technological model REES-SLO enables the simulation and evaluation of the instruments envisaged and their impacts, such as sets of instruments linked in strategies. The computational model links the effects of the various measures through a transparent model presentation, provides consistent assessments and provides a framework for a consistent and

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uniform approach to the identification of instruments, measures and final effects in different sectors and sub-sectors.

Depending on the details of the treatment, the set of models used in an integrated approach requires, more detailed simulation or optimisation models of individual energy system segments, which means that the models are interconnected at the input/output level or consider the same assumptions and co-influence the calculations.

## 1.4 Model results

In this section a few examples of the REES-SLO model results are presented. Technology-oriented simulation model REES-SLO was used in the energy policy development process as a framework for consistent and equal approach to the identification of instruments, measures and impacts in various energy sectors and subsectors. Also, the role of the developed REES-SLO model in the policy follow-up process is vitally important. With the comprehensive follow-up programme which will enable adaptive approach in policy implementation, chances for the overall success of the proposed energy policy are significantly higher. The results indicated the developed REES-SLO model could effectively address not only challenges associated with the power generation expansion decisions but also uncertainties presented in various formats. Open structure of MESAP proved to be suitable modelling tool for relatively small energy systems where many peculiarities have to be considered. The obtained solutions proved its usefulness in supporting decisions of energy systems planning at the state level. Figure bellow shows an example of the graphical representation of the REES-SLO calculation results for industrial sector. On the left-hand side, the fuel structure for the base year is presented, whilst on the right-hand side the structure for 2050 is presented.

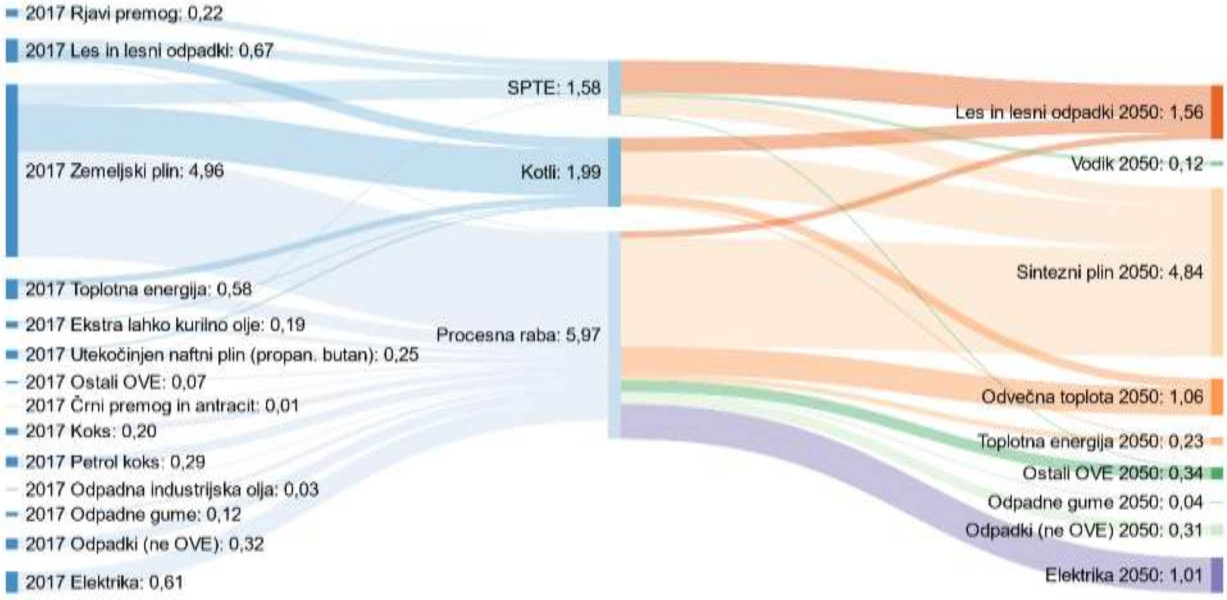

**Figure 6: Example of REES-SLO resulting calculations for industrial sector (2017 vs. 2050)**

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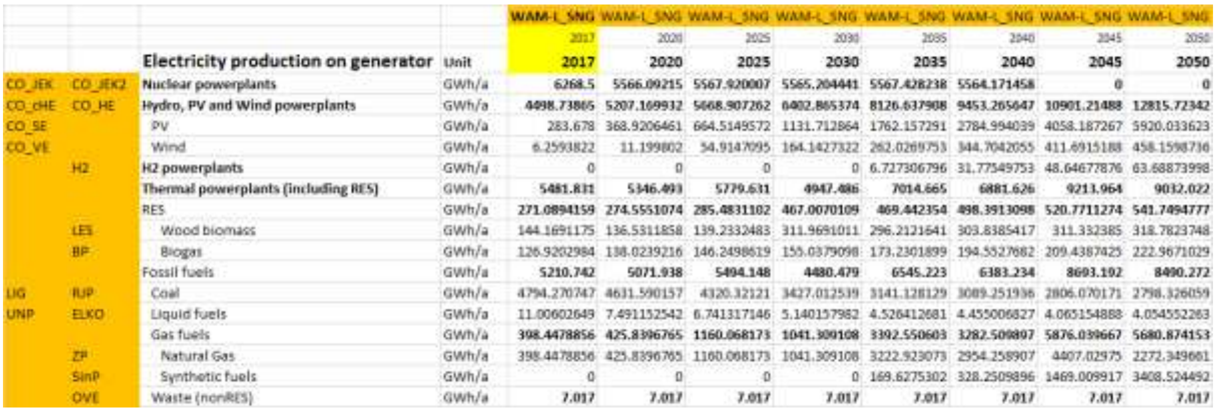
Another example is electricity production table for various different scenarios. As shown in figure below, table covers every combination of technology and fuel used that was, is and will be (in accordance with the scenario assumptions). The results are also divided by source of domestic electricity production technology.



| | | | | WAM-L_SNG | WAM-L_SNG | WAM-L_SNG | WAM-L_SNG | WAM-L_SNG | WAM-L_SNG | WAM-L_SNG | WAM-L_SNG |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
| | | **Electricity production on generator** | Unit | **2017** | **2020** | **2025** | **2030** | **2035** | **2040** | **2045** | **2050** |
| CO_JEK | CO_JEK2 | **Nuclear powerplants** | GWh/a | 6268.5 | 5566.09215 | 5567.920007 | 5565.204441 | 5567.428238 | 5564.171458 | 0 | 0 |
| CO_cHE | CO_HE | **Hydro, PV and Wind powerplants** | GWh/a | 4498.73865 | 5207.169932 | 5668.907262 | 6402.865374 | 8126.637908 | 9453.265647 | 10901.21488 | 12815.72342 |
| CO_SE | | PV | GWh/a | 283.678 | 368.9206461 | 664.5149572 | 1131.712864 | 1762.157291 | 2784.994039 | 4058.187267 | 5920.033623 |
| CO_VE | | Wind | GWh/a | 6.2593822 | 11.199802 | 54.9147095 | 164.1427322 | 262.0269753 | 344.7042055 | 411.6915188 | 458.1598736 |
| | H2 | **H2 powerplants** | GWh/a | 0 | 0 | 0 | 0 | 6.727306796 | 31.77549753 | 48.64677876 | 63.68873998 |
| | | **Thermal powerplants (including RES)** | GWh/a | 5481.831 | 5346.493 | 5779.631 | 4947.486 | 7014.665 | 6881.626 | 9213.964 | 9032.022 |
| | | RES | GWh/a | 271.0894159 | 274.5551074 | 285.4831102 | 467.0070109 | 469.442354 | 498.3913098 | 520.7711274 | 541.7494777 |
| | LES | Wood biomass | GWh/a | 144.1691175 | 136.5311858 | 139.2332483 | 311.9691011 | 296.2121641 | 303.8385417 | 311.332385 | 318.7823748 |
| | BP | Biogas | GWh/a | 126.9202984 | 138.0239216 | 146.2498619 | 155.0379098 | 173.2301899 | 194.5527682 | 209.4387425 | 222.9671029 |
| | | Fossil fuels | GWh/a | 5210.742 | 5071.938 | 5494.148 | 4480.479 | 6545.223 | 6383.234 | 8693.192 | 8490.272 |
| LIG | RJP | Coal | GWh/a | 4794.270747 | 4631.590157 | 4320.32121 | 3427.012539 | 3141.128129 | 3089.251936 | 2806.070171 | 2798.326059 |
| UNP | ELKO | Liquid fuels | GWh/a | 11.00602649 | 7.491152542 | 6.741317146 | 5.140157982 | 4.526412681 | 4.455006827 | 4.065154888 | 4.054552263 |
| | | Gas fuels | GWh/a | 398.4478856 | 425.8396765 | 1160.068173 | 1041.309108 | 3392.550603 | 3282.509897 | 5876.039667 | 5680.874153 |
| | ZP | Natural Gas | GWh/a | 398.4478856 | 425.8396765 | 1160.068173 | 1041.309108 | 3222.923073 | 2954.258907 | 4407.02975 | 2272.349661 |
| | SinP | Synthetic fuels | GWh/a | 0 | 0 | 0 | 0 | 169.6275302 | 328.2509896 | 1469.009917 | 3408.524492 |
| | OVE | Waste (nonRES) | GWh/a | 7.017 | 7.017 | 7.017 | 7.017 | 7.017 | 7.017 | 7.017 | 7.017 |

**Figure 7: Electricity production in WAM Low additional Synthetic Gas (L_SNG) scenario**

Another important aspect has to be highlighted at this point, REES-SLO model is a simulation model connected also to other types of models (optimisation, geographic information system models (GIS), computable general equilibrium models (CGI)), its free structure enables the connections with other types of models which is an important and useful feature for further development of the model. The figure bellow shows an example of a connection with GIS model to assess the potential for waste heat utilisation.

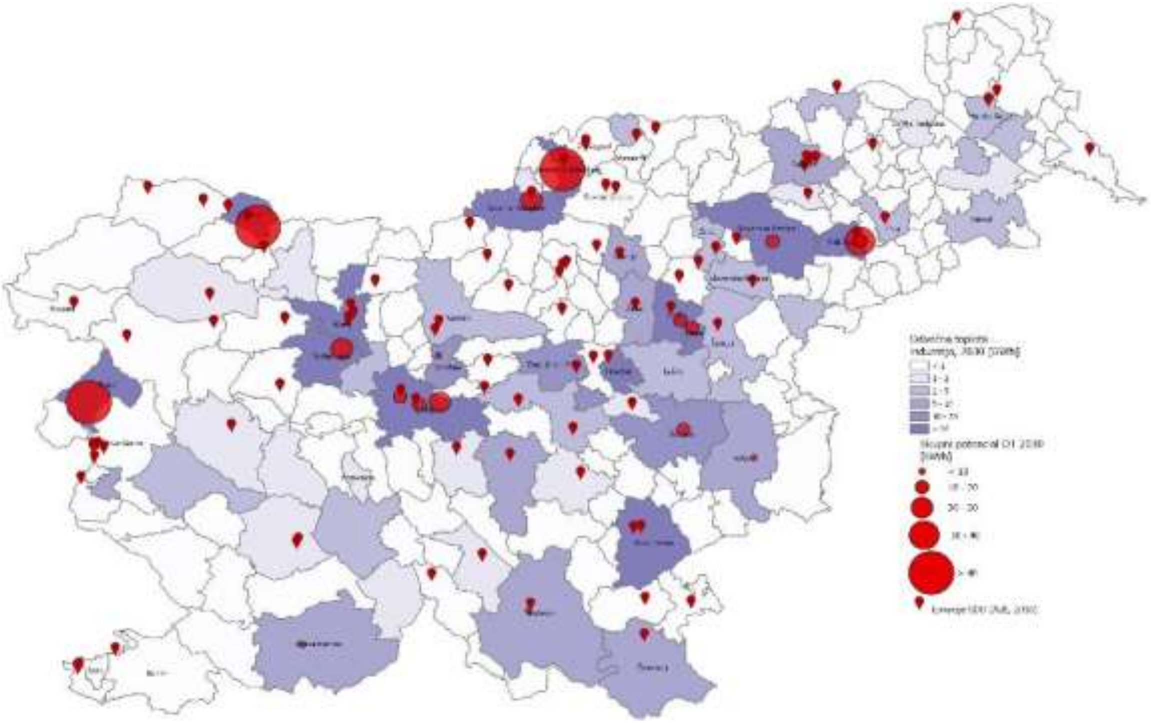


**Figure 8: Example of REES-SLO model connected to the GIS model for analysing the potential for waste heat utilisation in Slovenia**

## 1.5 Future development of the model and research challenges

The model requires constant updating and adaptation to changes, due to the improvements and availability of new statistical data, technology descriptions and external influencing factors. The following research challenges or fields can be highlighted in relation to the improvements of the REES-SLO model:

- improvements in the field of circular economy, resource efficiency, product design and sustainability;
- evaluation of socio-economic effects such as energy poverty and behaviour changes;
- addressing changes in the economic and social paradigm (energy efficiency vs. energy sufficiency);
- evaluation of the impact of scenarios on the structure of the economy in support of national strategies of economic development.

REES-SLO model along with other connected models and sub-models represent an overall methodological framework for assessing different decarbonisation pathways. The tools and models developed in the scope of LIFE ClimatePath 2050 enabled the transparent and consistent approach to policy development and implementation support. Nevertheless, it can be concluded that models have passed the applicability test, since the results were included in the National Energy and Climate Plan (NECP) of the Republic of Slovenia and the Resolution on the Slovenian Climate Long-Term Strategy 2050 (LTS).

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# Energy sector models

## 2.1 Other use, including households and services energy use

### 2.1.1 Purpose of the model

Building energy model is a part of REES-SLO model and is being used to calculate energy demand and overall final energy use in the building sector based on the energy efficiency of the thermal envelope and energy carrier used for the operation of the buildings (heating, cooling, domestic hot water preparation, ventilation and lighting). Based on the calculations on the entire building stock the GHG emissions and air pollutant emissions serve as an input to the emission calculation module and scenario analysis.

The building model has developed in order to enable better expert basis and knowledge in order to support strategic decisions-making towards decarbonisation of the building stock. Its main objective is to develop scenarios for the long-term development of energy demand, greenhouse gas emissions and air pollutant emissions for the building sector. It considers a broad range of mitigation options combined with a high level of technological detail.

The model can address various research questions related to energy demand, GHG and air pollutant emissions on the national scale in the building sector. Examples include scenarios for the future demand of individual energy carriers like electricity (important due to the increased rate of annual heat pump installation), fuel oil (important due to high amount of such boilers installed in Slovenian household and future replacements), biomass and also scenarios of penetration of synthetic fuels, calculations of energy saving potentials and their impact on GHG and air pollutant emissions, ex ante policy impact assessment low carbon transition scenarios.

During LIFE Climate Path 2050 project the following improvements of the model have been made:

- The entire model was updated and calibrated up to 2017 from the aspect of energy consumption the building sector as a reference point.
- The modelling of the buildings in the service sector has been extended and enables now more in-depth analysis.
- The scenarios of future fuel-based boilers phase out projections, that are dictated by national regulation, have been integrated through share of used technologies for heating.
- Modelling period has been prolonged. Previous model made calculations until 2030. In the updated model calculations are made until 2050.
- The building technology sub-model was upgraded and further connected with a new sub-model for district heating modelling, enabling more detailed of demand-supply analysis.

### 2.1.2 Model Inputs

*Influencing factors*

The main influence factors for REES building model are (1) number of households, (2) heated floor area and (3) temperature deficit and surplus. Each of those factors will be presented in short in the following sections.

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### Number of households

According to SURS's[2] data, in January 2017 there were 2,066,880 residents that lived in 800,780 private households in Slovenia. The number of joint households increased (from 435 to 497), but the number of residents in them was not significant (35,439). Most of them lived in dormitories for the elderly (18,000), student dormitories (10,700) and in social care institutions for children, youth or older (4,400).

After 2025, the population will be declining, but due to the decrease in the average household size, the total number of households is going to increase until 2050. In the base year 2017, the average household size was 2.52 members per household, while in 2030 the size will be 2.42. Ten years later, it will fall further to 2.34 in 792,568 inhabited dwellings, where there will be 860,141 households. There were 800,780 of these in the base year 2017 and 836,613 in 2030. By 2050, the number of households will increase by 84,626 compared to the base year 2017 to a total of 885,406, with the average household size further decreasing compared to 2040 to the final 2.25.

### Heated floor area

The heated floor area of buildings and their overall growth is crucial in understanding the energy efficiency of the building stock. The total floor area of the apartments, which is being heated in the heating season is considered.

The **residential building stock** is divided into single (SFH) and multi-family buildings (MFH). It is projected that the growth of new buildings will remain at the level of previous years until 2030, and by 2050 the growth will be lower. The total floor area of all residential buildings will thus amount to almost 68 million m2 in 2030, and 68.23 million m2 in 2050. The increase in the area of residential buildings is estimated on the basis of the growth in the number of households and the estimate of the current housing deficit.

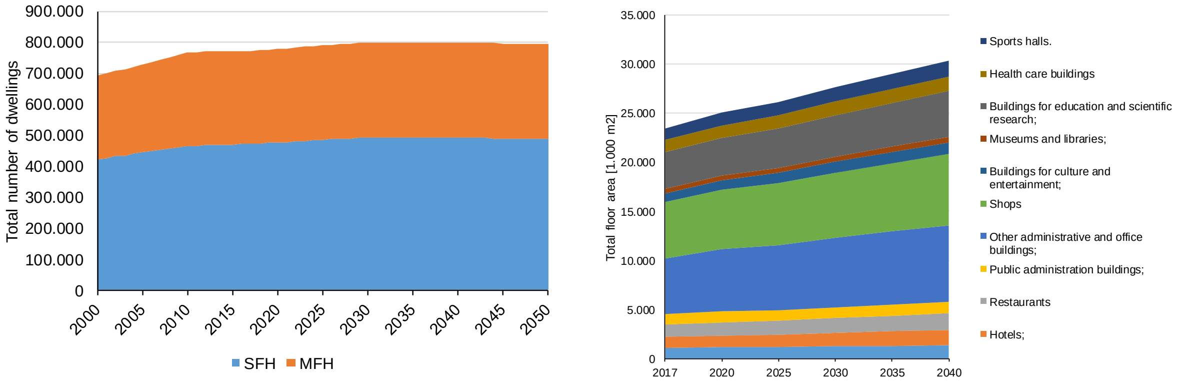

**Figure 9: Total number of dwellings by single-family houses (SFH) and single-family houses (MFH) buildings (left) and projection of the total floor area of buildings in the service sector (right) (source: SURS, JSI-CEU)**

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[2] SURS – Statistical Office of the Republic of Slovenia

The **non-residential building stock** is divided into 11 building types according to the use of spaces, the total area of which in 2017 amounted to 23.493 million m2. These are:

- residential buildings for special social groups;
- hotels;
- catering buildings;
- public administration buildings;
- other administrative and office buildings;
- shops;
- buildings for culture and entertainment;
- museums and libraries;
- buildings for education and scientific research;
- health care buildings and
- sports halls.

The growth of the area of buildings by 2030 and 2050 is projected to approximately the same extent as it was according to statistical data and data from the Real Estate Register in previous years. The total area of buildings will thus amount to 27.625 million m2 in 2030, 30.335 million m2 in 2040 and 32.921 million m2 in 2050. The buildings of the service sector are further considered in the model separately for the public sector and the rest of the service sector.

### *Temperature deficit and temperature surplus*

The projections of energy use until 2050 considered the results of the ARSO project Climate Change Assessment in Slovenia until the end of the 21st Century, within which the average changes of the most important climate variables were estimated. The course of climate change depends in particular on global greenhouse gas emissions, which have been captured for the purpose of this project using different scenarios of different greenhouse gas content flows (Representative Concentration Pathways - RCP). The results of the stabilization scenario RCP4.5 were used, which is considered moderately optimistic based on the current situation, envisages a gradual reduction of emissions and stabilization of the radiation contribution at 4.5 W / m by 2100. Future climate simulations are based on multi-model averages of simulations of different regional climate models. Six model simulations were performed for the RCP4.5 scenario and the median of the results was used. A threshold of 12 ° C and a conversion to an average temperature of 20 ° C were used for the temperature deficit and a threshold of 21 ° C for the excess of temperature. Averages for the whole of Slovenia were used, which were calculated weighted by the number of inhabitants and ten-year averages. The temperature deficit will decrease by 8% by 2050 compared to 2015. The change in the temperature surplus is significantly larger, increasing by 96% by 2050 compared to 2015.

### *Internal input parameters*

Internal input parameters contain policy parameters and a vast set of technology parameters including behavioural assumptions.

- In the general model:

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  - Measures that influence change people's behaviour (raising awareness, monitoring energy consumption, etc.) and optimization of the heating system (thermostatic valves, hydraulic balancing of the system, etc.).
  - Energy saving measures for lighting.
  - Progressive efficient use of residual electricity resulting from either cooling & ventilation or other electricity consumers (household appliances, lighting)
  - Energy consumption projections from household appliances.
- In the building energy demand sub-models:
  - Specific building energy demand by building’s type, age and possible levels of energy renovation.
  - Energy renovation rates up to 2050 by building type for different scenarios.
  - Final energy consumption by building type in residential building sector for model calibration.
  - Lifetime curves for material used for energy renovation.
  - Inclusion of cultural heritage buildings as the one where extensive energy renovation works on thermal envelope cannot be undertaken.
- In the building technical systems sub-models:
  - Share of installed technologies up to 2050 in residential building stock by (1) building type: single- and multi-family buildings, (2) technical system – its efficiencies and energy carriers and (3) dense and sparse areas.
  - Share of installed technologies up to 2050 in non-residential building stock by (1) building type: public buildings and other service sector buildings, (2) technical system – its efficiencies and energy carriers and (3) dense and sparse areas.
  - Efficiency of the technical systems for heating according to their age.
  - Projections of technical system penetration or its phase-out.
  - Specific energy consumption for ventilation, cooling and lighting according to building type and its projections up to 2050.
  - Lifetime curves for technical systems for heating.

### 2.1.3 Key assumptions, scenarios and border conditions

Four scenarios have been modelled and assessed with the REES buildings model:

- **Without measures WOM(BU)**: assuming there is no activity regarding improvement of energy efficiency and technical system modifications in buildings - no measures after 2015; no changes in technical system for heating structure, no improvement of efficiency of the thermal envelope, no energy renovations
- **With existing measures WEM(WEM(OU)):** building activity projections considering measures from Slovenian existing adopting document, support measures for alternative technologies slowly shifting structure of the heating systems, moderate improvement of efficiencies in buildings and use of renewable energy sources; considering all the measures that have been implemented or adopted before end of 2018 (also EU policies and measures)
- **With additional measures – moderate WAM(DU)**: additional measures supporting energy renovation of buildings and heating system replacement of inefficient boilers, mainly fuel oil and old biomass boilers, that contribute to building stock overall

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improvement, moderate increase of renovation rates and technical systems for heating penetration and phase-out, moderate increase of renewable energy sources exploitation

- **With additional measures – ambitious WAMa(DUA)**: high increase of renovation rates, quicker and more ambitious phase out of fuel-based systems for heating, bigger role of nearly-zero energy renovations as well as new build, very strong shift toward renewable energy sources and complete phase out of all fuel-based technologies until 2050, inclusion of synthetic technology for heating, very high efficiency improvement.

### 2.1.4 Model structure

*Methodology*

REES building energy model can be classified as:

- bottom up;
- long term;
- sectoral model;
- single node;
- space resolution – Slovenia;
- time resolution 2020-2050 with 5-year steps, Backward modelling done for the period 2005-2017 on a yearly basis;
- simulation;
- linear programming.

Model has been developed in excel and in the MESAP environment. Excel environment has been used for initial development and testing of the model and scenario assumptions, while final version of the model has been prepared in the MESAP environment.

*Energy demand calculation*

Building energy model is based on comprehensive analysis of the building stock that derives from national database. Based on available energy sources the energy demand for heating in cooling is calculated with separate sub-model. The model is based on building typology that depicts buildings in cohorts according to the (1) building's age, (2) type and (3) detected energy renovation works that were already performed and decrease the overall demand. The final result at this point presents technical potential for energy renovation from the starting point 2017 until 2050. According to defined energy renovation rates, the buildings are being slowly renovation and the technical potential decreased. Due to expired lifetime of materials, some building can be considered as a potential for energy renovation twice – firstly, at the beginning of the observed period and then just before 2050, when 30-year lifetime period expires. Furthermore, cultural heritage buildings were considered as a share of buildings in each building period where energy renovation cannot be undertaken.

The renovation rate for multi-family houses is higher than for single-family houses, but due to the higher share of dwellings in single-family houses, three quarters of renovations are attributed to single-dwelling buildings and one quarter to multi-family houses. Buildings of all ages are being renovated. From the energy point of view, the building belongs to a certain

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energy class (or energy label), which shows its state of energy demand for heating. During the energy renovation, the building passes between energy classes, as its energy efficiency is improved. The scope of energy renovation works can be different, with the following renovations being defined: standard renovation, improved renovation and low-energy renovation. A building that has not yet been energetically renovated can therefore be renovated in three different ways and its energy class is improved accordingly. The value of the energy class of an individual building depends on the type of building, the scope of the renovation and the age of the building.

For non-residential building sector, different levels of energy renovation were assumed according to the ownership. Due to national commitments of 3% renovation of public buildings, rates are expected to continue to be higher in public sector buildings. Due to obligations for more energy efficient renovations or nearly zero-energy renovations, the scope of more comprehensive renovations will increase.

Outputs from the energy demand sub-model is total energy demand for heating per building type.

### *Energy supply calculation*

The ability to create projections of technology market share derives from the past trends. Market share for each technology for heating is calibrated according to the building type and location – dense or sparse area from 2012 up to 2017. Such in-depth model enables to take into account different technology penetration structure in different areas.

The structure of fuels in the residential building sector was modelled separately in densely populated and sparsely populated areas and separately for single- and multi-family buildings. Single-family buildings in particular are characterized by a significant increase in the share of heat pumps in all areas: in densely populated areas, the share rises from 7.3% in baseline to 51.6% in 2050 in the WAMa(DUA) scenario and from 9.8% to 27.4% in 2050 in sparsely populated areas. In line with the national adopted documents, the use of fossil fuel boilers will be reduced. Fuel oil in the dense areas represents a 36.9% share in the base year and 8.4% in the sparse areas. The use of heating oil is almost halved by 2030, and by 2050 only a minimal share remains.

Replacement of boilers for heating oil and natural gas will take place in the densely populated areas primarily with new connections to district heating and the installation of heat pumps, and in the sparse areas in addition to these also with installation of new, more efficient wood biomass boilers, where the share from the base year 2017 of 70.3% will be slightly reduced to 66% in 2050 according to the WAMa(DUA) scenario. A similar logic was applied to multifamily buildings. A small share of biomass connections in the dense areas is maintained (from 1.7% in the base year to 4.2% in the WAMa(DUA) scenario in 2050), but increases in sparse areas (35.6% in 2030 and 45.6% in the WAMa(DUA) scenario) in 2050). The share of heating oil in the base year is 8.5% in the dense areas and 29.2% in the sparse areas - in both areas this share will be almost 0% by 2050 in all scenarios. The share of natural gas boilers will be halved, the rest are primarily multi-storey gas condensing boilers, the replacement of which with another

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energy source via central heating is economically questionable and requires additional studies to address this issue.

The projections in the service sector envisage a significant reduction in the use of heating oil due to an increase in the use of RES (biomass boilers and heat pumps), district heating and gas (CHP units and natural gas and LPG boilers). The increase in the share of natural gas in useful energy is associated with CHP. Developments in the public and other service sectors differ in particular in that the private service sector is projected to have a significantly higher penetration of district heating systems, which means that the share of RES is lower than in the public sector. In the WAMa(DUA) scenario, the share of district heating in the public sector is higher by 8 and in the rest of the service sector by 16 percentage points compared to the scenario with existing measures. A detailed analysis showed that 56% of the total useful heat in public sector buildings and 59% of the total useful heat of buildings in the rest of the service sector are located in an area with dense population and a minimum consumption of 100 MWh / ha.

Outputs from the energy supply sub-model is market share of the technology for heating by building type separately for dense and sparse areas.

### *Overall building energy model*

The final stage of modelling presents the energy demand-supply analysis where final energy use per energy source is calculated through market share of a certain technology by the building type and its overall energy demand. The final results are presented as energy balance of the entire building stock per year and pear energy sources.

### *Technologies, sectors, processes*

Detailed description of the modelled technologies that were presented in the previous chapter and their characteristics is provided in this chapter.

Renovation rates are more intensive with each scenario, which is consequently reflected in a faster reduction of the technical potential for energy renovation. The WAMa(DUA) scenario envisages the highest rates of renovations, with the rate of renovations falling sharply after 2040 due to reduced technical potential. The tables below show the structure of areas by energy classes for the WEM(OU), WAM(DU) and WAMa(DUA) scenarios, separately for single- and multi-family buildings.

**Tab. 1: Structure of total floor areas of single-family buildings according to the construction period, energy class and scenarios WEM(OU), WAM(DU) and WAMa(DUA) (source: JSI-EEC)**

| Construction period | Energy class | Energy demand | Total floor area [1.000 $m^2$] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Scenario WEM(OU) | | Scenario WAM(DU) | | Scenario WAMa(DUA) | |
| | [-] | [kWh/$m^2$] | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| **Before 1945** | **Unrenovated** | 185 | 3.877 | 1.444 | 1.419 | 1.443 | 1.418 | 1.443 | 1.418 |
| | **Partly r.** | 151 | 4.476 | 5.088 | 5.088 | 4.996 | 4.996 | 5.094 | 5.094 |
| | **Improved r.** | 77 | 1.080 | 966 | 964 | 966 | 964 | 966 | 964 |

| Construction period | Energy class | Energy demand | Total floor area [1.000 $m^2$] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Scenario WEM(OU) | | Scenario WAM(DU) | | Scenario WAMa(DUA) | |
| | [-] | [$kWh/m^2$] | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| | **Low-energy r.** | 35 | 247 | 2.166 | 2.168 | 2.259 | 2.261 | 2.161 | 2.163 |
| **1946 – 1970** | **Unrenovated** | 177 | 1.239 | 211 | 211 | 211 | 211 | 211 | 211 |
| | **Partly r.** | 151 | 5.620 | 2.742 | 1.807 | 2.363 | 1.747 | 2.327 | 1.711 |
| | **Improved r.** | 77 | 1.466 | 2.389 | 1 | 2.030 | 1 | 1.722 | 1 |
| | **Low-energy r.** | 35 | 247 | 2.677 | 5.385 | 3.415 | 5.444 | 3.760 | 5.481 |
| **1971 – 1980** | **Unrenovated** | 164 | 3.510 | 156 | 156 | 157 | 157 | 158 | 158 |
| | **Partly r.** | 111 | 2.797 | 2.760 | 257 | 2.043 | 235 | 1.604 | 229 |
| | **Improved r.** | 77 | 1.742 | 2.590 | 1 | 2.596 | 1 | 2.787 | 1 |
| | **Low-energy r.** | 35 | 222 | 2.219 | 6.564 | 2.928 | 6.585 | 3.176 | 6.590 |
| **1981 – 2002** | **Unrenovated** | 107 | 8.717 | 2.733 | 219 | 1.691 | 222 | 767 | 223 |
| | **Partly r.** | 90 | 3.839 | 4.949 | 1.026 | 4.784 | 858 | 5.225 | 757 |
| | **Improved r.** | 77 | 679 | 2.073 | 671 | 2.340 | 1 | 2.578 | 1 |
| | **Low-energy r.** | 35 | 305 | 3.305 | 10.396 | 4.244 | 11.232 | 4.489 | 11.331 |
| **2003 – 2008** | **Unrenovated** | 80 | 1.495 | 1.412 | 43 | 1.394 | 43 | 1.374 | 42 |
| | **Improved r.** | 55 | 1.087 | 1.095 | 949 | 1.090 | 565 | 1.100 | 161 |
| | **Low-energy r.** | 35 | 136 | 192 | 1.452 | 215 | 1.836 | 225 | 2.242 |
| **After 2008** | **Unrenovated** | 56 | 2.939 | 3.343 | 1.928 | 3.343 | 1.553 | 3.343 | 1.124 |
| | **Low-energy r.** | 15 | 1.103 | 5.166 | 9.789 | 5.166 | 10.164 | 5.166 | 10.593 |

**Tab. 2: Structure of total floor areas of multi-family buildings according to the construction period, energy class and scenarios WEM(OU), WAM(DU) and WAMa(DUA) (source: JSI-EEC)**

| Construction period | Energy class | Energy demand | Total floor area [1.000 $m^2$] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Scenario WEM(OU) | | Scenario WAM(DU) | | Scenarij WAMa(DUA) | |
| | [-] | [$kWh/m^2$] | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| **Before 1945** | **Unrenovated** | 133 | 940 | 447 | 438 | 447 | 438 | 447 | 438 |
| | **Partly r.** | 98 | 1.655 | 1.913 | 1.913 | 1.897 | 1.897 | 1.845 | 1.845 |
| | **Improved r.** | 75 | 345 | 301 | 300 | 301 | 300 | 301 | 300 |
| | **Low-energy r.** | 25 | 72 | 344 | 345 | 351 | 352 | 361 | 362 |
| **1946 – 1970** | **Unrenovated** | 144 | 497 | 90 | 90 | 90 | 90 | 90 | 90 |
| | **Partly r.** | 98 | 2.908 | 1.205 | 981 | 1.194 | 970 | 1.194 | 970 |
| | **Improved r.** | 75 | 805 | 1.665 | 0 | 793 | 0 | 909 | 0 |
| | **Low-energy r.** | 25 | 97 | 1.144 | 2.809 | 2.027 | 2.820 | 1.911 | 2.820 |
| **1971 – 1980** | **Unrenovated** | 134 | 1.291 | 85 | 79 | 73 | 73 | 73 | 73 |
| | **Partly r.** | 75 | 1.532 | 1.049 | 131 | 341 | 83 | 390 | 82 |
| | **Improved r.** | 58 | 862 | 1.674 | 0 | 1.897 | 0 | 2.017 | 0 |

| Construction period | Energy class | Energy demand | Total floor area [1.000 m²] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Scenario WEM(OU) | | Scenario WAM(DU) | | Scenarij WAMa(DUA) | |
| | [-] | [kWh/m²] | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| | **Low-energy r.** | 25 | 64 | 740 | 3.066 | 1.237 | 3.120 | 1.069 | 3.122 |
| **1981 – 2002** | **Unrenovated** | 90 | 2.383 | 281 | 72 | 73 | 73 | 73 | 73 |
| | **Partly r.** | 75 | 1.047 | 1.744 | 212 | 1.271 | 139 | 1.360 | 139 |
| | **Improved r.** | 58 | 279 | 1.015 | 0 | 1.077 | 0 | 1.090 | 0 |
| | **Low-energy r.** | 25 | 92 | 586 | 3.070 | 1.205 | 3.143 | 1.104 | 3.143 |
| **2003 – 2008** | **Unrenovated** | 66 | 742 | 697 | 18 | 681 | 18 | 675 | 17 |
| | **Improved r.** | 49 | 433 | 438 | 259 | 439 | 11 | 441 | 11 |
| | **Low-energy r.** | 25 | 62 | 95 | 860 | 111 | 1.109 | 114 | 1.109 |
| **After 2008** | **Unrenovated** | 49 | 708 | 794 | 340 | 794 | 158 | 794 | 97 |
| | **Low-energy r.** | 15 | 100 | 986 | 2.484 | 986 | 2.667 | 986 | 2.728 |

According to the scenario with existing measures, by 2030, compared to 2017, 30% of the total building stock will remain non-renovated, according to the WAM(DU) scenario 26% and according to the WAMa(DUA) scenario 24%. Renovations differ from each other in terms of scope and structure - partial or improved renovations and comprehensive or further improved renovations. The volume of non-renovated buildings will decrease over the years and in 2050, on average, 10% of all areas will remain in all scenarios.

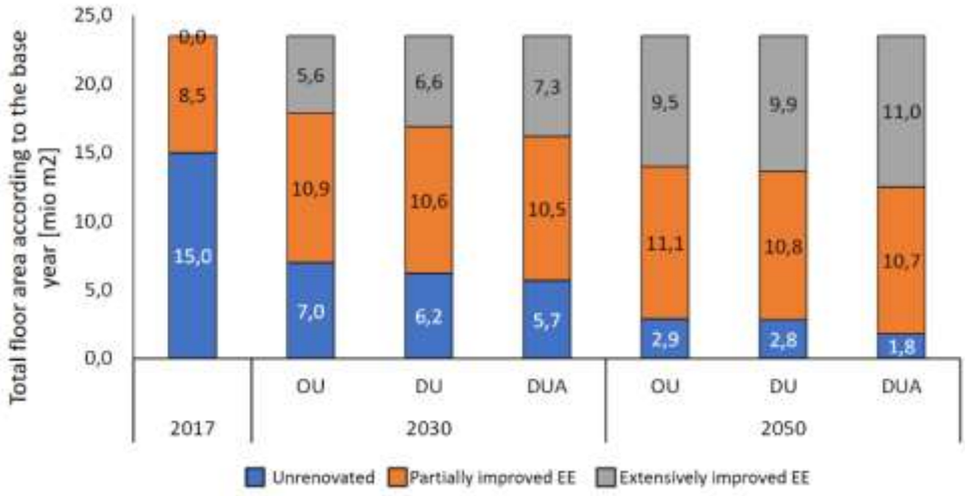

**Figure 10: Structure of areas of buildings in the service sector according to the extent of renovation works for 2017, 2030 and 2050, where energy efficiency (EE) is going to be improved (source: JSI-EEC)**

An increase in the share of improved boilers is achieved by encouraging the purchase of new improved boilers and the replacement of the use of old boilers. Furthermore, WAM(DU) and WAMa(DUA) scenarios consider that in densely populated areas, the replacement of old, inefficient boilers is encouraged by the either connections to the district heating grid either heat

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pumps. In sparsely populated areas, the replacement of old fossil fuel boilers is encouraged by replacing either biomass boilers or heat pumps.

**Tab. 3: Structure of heating technologies in single-family buildings for WEM(OU), WAM(DU) and WAMa(DUA) scenarios in densely populated areas for the base year, 2030 and 2050 (JSI-EEC)**

| Energy source | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Coal | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Biomass | 16.9% | 16.0% | 18.4% | 18.3% | 12.5% | 17.2% | 16.8% |
| Fuel oil | 36.9% | 10.4% | 10.4% | 10.0% | 0.4% | 0.4% | 0.2% |
| Natural Gas | 32.6% | 32.9% | 30.5% | 29.5% | 19.5% | 11.4% | 4.0% |
| District heating | 5.5% | 8.2% | 9.2% | 9.7% | 13.0% | 18.5% | 23.2% |
| Heat pumps | 7.3% | 31.2% | 30.3% | 31.3% | 50.1% | 48.2% | 51.6% |
| Electricity | 0.7% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Micro CHP | 0.0% | 1.0% | 1.0% | 1.0% | 4.2% | 3.9% | 3.8% |
| Solar heating | 0.1% | 0.2% | 0.2% | 0.2% | 0.4% | 0.4% | 0.4% |

**Tab. 4: Structure of heating technologies in single-family buildings for WEM(OU), WAM(DU) and WAMa(DUA) scenarios in sparsely populated areas for the base year, 2030 and 2050**

| Energy source | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Coal | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Biomass | 70.3% | 54.0% | 55.4% | 56.0% | 56.3% | 62.5% | 66.0% |
| Fuel oil | 8.4% | 6.6% | 6.6% | 6.1% | 2.1% | 2.1% | 0.5% |
| Natural Gas | 9.2% | 11.8% | 10.5% | 10.3% | 11.4% | 3.5% | 1.6% |
| District heating | 1.3% | 2.5% | 2.5% | 2.5% | 4.2% | 4.2% | 4.2% |
| Heat pumps | 9.8% | 24.9% | 24.9% | 24.9% | 25.7% | 27.4% | 27.4% |
| Electricity | 0.9% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Micro CHP | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Solar heating | 0.1% | 0.1% | 0.1% | 0.1% | 0.3% | 0.3% | 0.3% |

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**Tab. 5: Structure of heating technologies in multi-family buildings for WEM(OU), WAM(DU) and WAMa(DUA) scenarios in densely populated areas for the base year, 2030 and 2050 (JSI-EEC)**

| Energy source | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Coal | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Biomass | 1.7% | 4.4% | 4.2% | 3.9% | 6.5% | 6.1% | 4.2% |
| Fuel oil | 8.5% | 3.2% | 3.2% | 3.2% | 0.0% | 0.0% | 0.0% |
| Natural Gas | 31.4% | 27.4% | 26.9% | 25.9% | 17.6% | 14.6% | 11.8% |
| District heating | 56.9% | 57.0% | 58.0% | 58.8% | 62.3% | 67.7% | 73.4% |
| Heat pumps | 0.6% | 7.5% | 7.2% | 7.7% | 12.5% | 10.7% | 9.9% |
| Electricity | 0.9% | 0.1% | 0.1% | 0.1% | 0.0% | 0.0% | 0.0% |
| Micro CHP | 0.0% | 0.4% | 0.4% | 0.4% | 1.0% | 0.8% | 0.7% |
| Solar heating | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |

**Tab. 6: Structure of heating technologies in multi-family buildings for WEM(OU), DU and WAMa(DUA) scenarios in sparsely populated areas for the base year, 2030 and 2050 (JSI-EEC)**

| Energy source | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Coal | | | | | | | |
| Biomass | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Fuel oil | 28.4% | 35.3% | 35.3% | 35.6% | 45.2% | 46.0% | 45.6% |
| Natural Gas | 29.2% | 9.0% | 9.0% | 9.0% | 0.1% | 0.1% | 0.1% |
| District heating | 26.6% | 29.4% | 29.4% | 29.0% | 20.0% | 18.6% | 17.0% |
| Heat pumps | 13.5% | 16.0% | 16.0% | 16.0% | 18.5% | 18.5% | 18.5% |
| Electricity | 1.5% | 9.8% | 9.8% | 9.9% | 16.0% | 16.5% | 18.5% |
| Micro CHP | 0.8% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% | 0.0% |
| Solar heating | 0.0% | 0.3% | 0.3% | 0.3% | 0.1% | 0.1% | 0.1% |

The analysis showed that there is a large, untapped potential in public and other service sector buildings and connections to district heating systems. A significant proportion of these buildings are located in densely populated areas, where either a district heating system already exists or there is potential for the construction of a new one. Depending on the different scenarios, different levels of connections to district heating systems are envisaged, with the WAMa(DUA) scenario accounting for slightly more than 23.3% of the total heat demand from district systems in the public sector in 2030. In the case of buildings in the rest of the service sector, this potential is more significant, as it could cover 44.1% of all needs.

**Tab. 7: Structure of heating technologies in the public sector for the scenarios WEM(OU), DU and WAMa(DUA) for the base year, 2030 and 2050 (source: JSI-EEC)**

| Energy source | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Biomass | 12.8% | 35.4% | 32.4% | 31.7% | 36.0% | 28.8% | 17.7% |
| LQP | 9.7% | 1.4% | 1.3% | 1.3% | 0.0% | 0.0% | 0.0% |
| Natural gas | 10.1% | 5.1% | 4.8% | 5.0% | 4.1% | 3.9% | 0.5% |
| Fuel oil | 30.5% | 4.1% | 4.2% | 4.6% | 0.0% | 0.0% | 0.0% |
| CHP | 4.3% | 1.3% | 4.3% | 4.7% | 1.2% | 1.3% | 1.4% |
| Environment | 10.2% | 33.2% | 28.8% | 26.8% | 38.8% | 39.9% | 52.6% |
| Solar heating | 0.0% | 0.2% | 0.3% | 0.5% | 0.3% | 0.5% | 0.8% |
| District heating | 18.0% | 17.4% | 21.8% | 23.3% | 18.4% | 24.9% | 26.4% |
| Electricity | 4.4% | 2.1% | 2.1% | 2.1% | 1.0% | 0.6% | 0.5% |

**Tab. 8: Structure of heating technologies in the other service building sector for the scenarios WEM(OU), DU and WAMa(DUA) for the base year, 2030 and 2050 (source: JSI-EEC)**

| Energy source | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Biomass | 8.3% | 21.8% | 14.2% | 5.4% | 17.4% | 12.9% | 2.1% |
| LQP | 5.1% | 0.7% | 0.4% | 0.2% | 0.0% | 0.0% | 0.0% |
| Natural gas | 7.7% | 8.9% | 5.1% | 1.9% | 7.2% | 2.9% | 0.1% |
| Fuel oil | 15.1% | 1.9% | 1.2% | 0.5% | 0.0% | 0.0% | 0.0% |
| CHP | 9.2% | 1.4% | 8.1% | 8.8% | 1.4% | 1.4% | 1.5% |
| Environment | 19.1% | 35.6% | 33.4% | 36.2% | 40.9% | 39.8% | 34.8% |
| Solar heating | 0.2% | 0.4% | 0.6% | 0.9% | 0.6% | 0.9% | 1.3% |
| District heating | 30.8% | 27.2% | 34.9% | 44.1% | 31.5% | 41.5% | 59.6% |
| Electricity | 4.5% | 2.2% | 2.2% | 2.2% | 1.0% | 0.6% | 0.5% |

### *Connections with other models*

REES building energy model uses three main sub-models as an input. Two main ones are models for the calculation of energy demand and technology projections. This serve as the main input for overall final energy balance calculation. Additionally, the model can take as an input result from district heating model, where an extensive bottom-up analysis can be done and realistic abilities for district heating penetration in the heating system structure.

### *Future development of the model and research challenges*

Future development can be extended in several ways:

1. **Better cross-sectors connectivity**: connections with energy supply model of with electricity market and district heating sector is pivotal for decision-making in the building

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sector, so the models will have to be further upgraded in a manner they’ll enable more in-depth analysis on micro level.

2. **Better modelling of effect** of measures on model parameters **– connection between measures/instrument and model parameters**: Implementation of different decision models in the REES Building model.
3. **Further upgrade of non-residential building typology:** extreme architectural diversity, insufficient list of installed technologies for building operation in public and other service building require a unique and detailed building typology. Although a major breakthrough was made in the scope of LIFE ClimatePath2050 project, there’s still much more research to be done in the future in order to analyse the stock as detailed as the residential building stock.
4. **Use of other environment** for the development of the model – e.g. Python to enable more flexible development allowing faster update of the model and faster preparation of different scenarios and better-quality management.
5. **Better integration between building energy renovation model and economic model** that will enable faster and parallel estimation of costs of different energy renovation measures. Combining the results with the past trend it will enable to make more realistic projections of overall possible renovation extent on the building stock.

### 2.1.5 Model results

Consumption of energy use is decreasing in all scenarios, as shown in the figure below. In 2030, compared to the base year 2017, according to the scenario with existing measures, the WEM(OU) is lower by 15% and amounts to 1,449 ktoe (60.7 PJ), and in 2050 it is still 4 percentage points lower with 1,372 ktoe (57.4 PJ). Compared to the scenario with existing WEM(OU) measures, the WAM(DU) and WAMa(DUA) scenarios envisage an even higher rate of energy renovations, greater emphasis on RES technologies for heating and hot water preparation, as well as a larger number of connections to district heating systems and a significant increase in their number in economically justified areas, which results in even lower energy consumption. In 2030, the final energy consumption will be reduced by 21% according to the WAMa(DUA) scenario and amounts to 1,340 ktoe (56.1 PJ), while by 2050 it will be further reduced by another 6 percentage points to the final 1,241 ktoe (51.9 PJ). According to the BU scenario, final energy consumption would increase by 8.7% by 2030 and amount to 1,841 ktoe (77.0 PJ), and by 2050 it would increase by an additional 6.1 percentage points and amount to 1,949 ktoe (81.6 PJ). Final energy use in the consumer sector for the scenarios until 2050 is presented in figure below.

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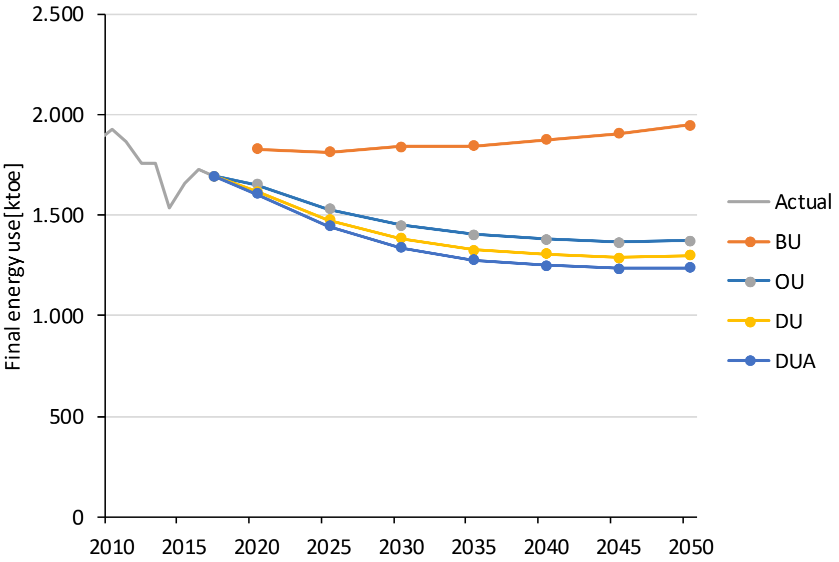

**Figure 11: Final energy use in the consumer sector for the scenarios until 2050 (source: JSI-EEC).**

Policies towards net zero emissions in final energy use by 2050 leads to a significant restructuring of the energy structure. Technologies that use fossil fuels will be replaced either by technologies that use RES or by heating sub-stations and connections to district heating systems. According to the scenario with the existing measures, the use of liquid fuels is expected to decrease by 78% in 2050 compared to 2017 and their use in 2050 is 2.6 PJ. According to the WAM(DU) scenario, their use will be further reduced by 2050 and amount to 1.6 PJ. According to the WAMa(DUA) scenario, the use of liquid fuels is projected to decrease by 94% to 0.8 PJ in 2050.

The main energy source remains electricity. Projections show an increase in electricity consumption due to (1) an increase in the share of heat pumps as heating technologies in buildings in new constructions and replacements of old, inefficient systems, (2) an increase in electricity consumption of other technical systems in buildings (lighting, cooling) and (3) increasing the use of electricity by other equipment, where the service sector is a large consumer. According to the scenario with the existing WEM(OU) measures, the use of electricity is expected to increase by 11% in 2030, when the use amounts to 27.5 PJ, and by 2050 it will further increase by 18 percentage points to 31.7 PJ. The WAMa(DUA) scenario also envisages a higher rate of replacements and uses of heat pumps, as well as more efficient lighting, more rational use and more efficient other equipment, etc. Therefore, electricity consumption increases less compared to the WEM(OU) by 2% to 25.2 PJ compared to 2017, while after this year due to restructuring it starts to increase faster, so that in 2050 from 28.5 PJ by 16 % higher than in 2017. Projection of energy use and structure in the service building sector for the various scenarios is shown in figure below.

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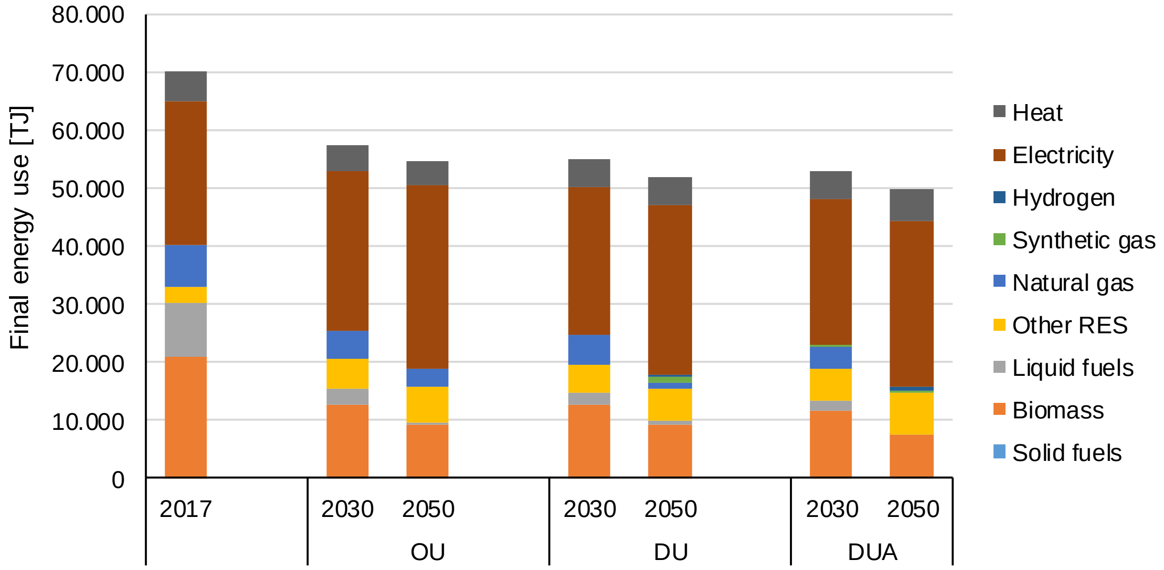

**Figure 12: Projection of energy use and structure in the service building sector for the various scenarios**

A significant reduction in energy consumption is projected in the household sector. According to the WEM(OU) scenario, from the base year 2017, when final energy consumption was 46.9 PJ, it will decrease by 26% (34.9 PJ) by 2030 and by an additional 12 percentage points by 2050 (28.9 PJ). Due to the envisaged orientations in the selection of technologies and lower heating needs, the final energy consumption in the WAMa(DUA) scenario is further reduced by 30% (32.6 PJ) by 2030 compared to the base year and by an additional 15 percentage points (26.0 PJ) by 2050. The use of fossil fuels is significantly reduced in all scenarios, especially for liquid fuels (89% reduction under the WEM(OU) scenario and 98% under the WAMa(DUA) scenario by 2050) and natural gas (57% reduction under the WEM(OU) scenario) and 94% under the WAMa(DUA) scenario by 2050), partly due to replacement with synthetic gas.

The main source of energy in services is electricity. Its share in 2017 is 56%. Use and share will gradually increase due to a larger number of heat pump installations as well as more extensive use of electrical appliances. Compared to the base year 2017 (12.6 PJ), according to the WEM(OU) scenario, use will increase by 14% (14.4 PJ) by 2030 and by as much as 44% (18.2 PJ) by 2050. The WAMa(DUA) scenario envisages more efficient use of electrical appliances and systems that will be more efficient, so the use itself does not increase as in the WEM(OU) scenario by 3% by 2030 (13.0 PJ) and by 33% by 2050 (16.7 PJ)).

Services are also characterized by an increase in the number of connections to remote systems, which is also reflected in the greater use of district heat. Compared to the base year, when this use was 2.1 PJ, according to the WAMa(DUA) scenario, by 2030 the use will increase by 7% (2.3 PJ) and by 34% (2,835 TJ) by 2050. It will also increase sharing of RES sources, and it should be noted that the statistics on the use of RES are deficient, as it does not contain data on the use of wood biomass and the use of RES due to heat pumps. For the needs of projections, the use of wood in 2017 was estimated at 1.2 PJ, and the use of environmental energy with heat pumps at 0.4 PJ. The final use of wood biomass will decrease by 21% (1.0 PJ) compared to the estimated use in the base year (1.2 PJ) according to the WAMa(DUA)

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scenario, but on the other hand the use of other RES (especially environmental energy) will increase significantly. The use of these in 2017 amounted to 0.9 PJ and according to the WAMa(DUA) scenario, by 2030 it will increase to 1.7 PJ or by 78%, and by 2050 to 2.5 PJ, which is a 162% increase over the base year. Projection of the share of RES in households (left) and services (right) is presented below.

**Figure 13: Projection of the share of RES in households (left) and services (right) (source: JSI-EEC)**

The share of RES in final use without electricity and remote systems in households accounted for 67% in the base year, while in service buildings 28%. Due to the restructuring of technologies in energy renovations of buildings, more rational orientation in new constructions and renovations in densely and sparsely populated areas, the share will continuously increase. Thus, according to the WAMa(DUA) scenario, the share of RES in final use will be 75% in households by 2030, and a 96% share by 2050. In the service buildings sector, the share will also increase significantly to 67% by 2030 under the WAMa(DUA) scenario and by an additional 15 percentage points by 2050. The growth of the share in services under the WAMa(DUA) scenario is lower than in WAM(DU) and WEM(OU), which is due to a smaller increase in end-use and a greater number of connections to remote systems.

## 2.2 Transport energy demand model

### 2.2.1 Purpose of the model

Energy and emissions transport model (REES transport) is being used to calculate energy consumption in the transport sector based on transport activity that is an output from the PRIMOS transport model and also GHG emissions and air pollutant emissions from the transport sector.

REES transport model has been developed to support strategic decisions toward low carbon society. Its main objective is to develop scenarios for the long-term development of energy demand, greenhouse gas emissions and air pollutant emissions for the transport sector. It considers a broad range of mitigation options combined with a high level of technological detail. Technology diffusion and stock turnover are explicitly considered to allow insights into transition pathways and speed.

The model can address various research questions related to energy demand, GHG and air pollutant emissions on the national scale in the transport sector. Examples include scenarios for the future demand of individual energy carriers like electricity, liquid biofuels, synthetic fuels also scenarios of penetration of alternative vehicle technologies, calculations of energy saving potentials and their impact on GHG and air pollutant emissions, ex ante policy impact assessment low carbon transition scenarios.

During LIFE Climate Path 2050 project the following improvements of the model have been made:

- PRIMOS and REES Transport models have been connected meaning that output from PRIMOS model was adjusted so that it could be used in REES Transport model as an input. Output from PRIMOS model is transport activity per average working day per different transport modes;
- modelling period has been prolonged; previous model made calculations until 2030: in the updated model calculations are made until 2050;
- new vehicle fleet models were made from scratch; models are done for all types of vehicles – cars, light duty vehicles, heavy duty trucks, separately for tractor trucks, buses; new input data have been used, new technologies were added, modelling period was prolonged to 2055, driven kilometres were added to the model, energy consumption of new vehicles was added enabling calculation of average energy consumption of the fleet per, emission factors were added to the model enabling more detailed modelling of evolution of average emission factors, new output masks have been prepared;
- the main energy model was upgraded enabling inclusion of additional vehicle technologies and new energy carriers; the model was also upgraded enabling easier addition of new scenarios;
- emissions model was upgraded enabling use of emission factors from the vehicle fleet models and more detailed modelling of emissions, black carbon (BC) was added to the list of air pollutants modelled;

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### 2.2.2 Model Inputs

*External influencing factors*

The main influence factor for REES Transport model is transport activity. What influences transport activity is described in the section *2.3 Transport activity model PRIMOS*. Other external influence factors are fuel prices – having effect on structure of first-time registered vehicles. Along fuel prices structure of first-time registered vehicles is strongly influenced by prices of vehicles. All these factors are considered when different scenarios for structure of first-time registered vehicles have been prepared.

GDP has been used for estimation of energy use in the aviation sector. Past data shows that there is quite good correlation between GDP and use of energy in the aviation sector in Slovenia.

*Internal Input Parameters*

Internal input parameters contain policy parameters and a huge set of technology parameters including behavioural assumptions:

- In the vehicle fleet models
    - Share of different vehicle technologies per vehicle category for first time registered vehicles
    - Distribution of first-time registered vehicles per age
    - Lifetime curves for vehicles
    - Driven kilometres per vehicle category, vehicles technology and age of vehicle
    - Energy consumption per vehicle category, vehicle technology and age of vehicle
    - Emission factors per EURO class of vehicles for CH4, N2O, NMVOC, NOx, PM TSP, PM 10, PM 2.5, BC, NH3 – source COPERT model
- REES Transport model (Figure 14)
    - Load or occupancy factors per vehicle category
    - Share of kilometres driven with fossil fuel for PHEV
    - Share of train kilometres driven on electricity
    - Specific consumption for trains, motors and mopeds
    - Share of domestic vehicles buying fuel abroad, share of foreign vehicles buying fuel in Slovenia per vehicle category
    - Share of biofuel in fossil fuel use in transport per type of biofuel (biofuels from cereal and other starch reach crops – 3(4) first paragraph, part A and B of Annex IX of RES directive, biogas)
    - Share of synthetic gas in gas consumption
    - Other energy consumption in transport
    - Ratio of aviation energy use per GDP

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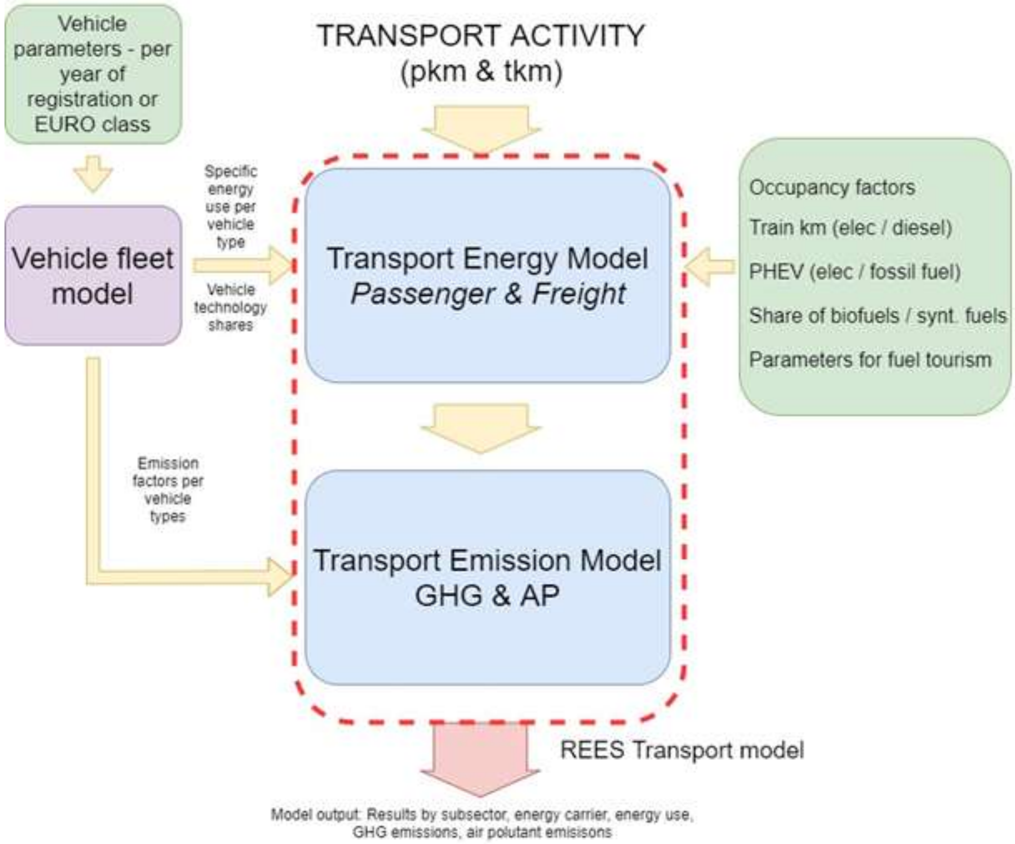

**Figure 14: REES Transport model scheme**

### 2.2.3 Key assumptions, scenarios and border conditions

Four main scenarios have been modelled:

- **Without measures WM(BU)**: assuming transport activity with no measures after 2015; vehicle fleet projection – no changes in structure, slow improvement in efficiency, no alternative fuels;
- **With existing measures WEM(WEM(OU)):** transport activity projections considering measures from Slovenian transport strategy and transport programme, support measures for alternative technologies slowly shifting structure of vehicles to alternative technologies, moderate improvement of efficiencies and use of biofuels; considering all the measures that have been implemented or adopted before end of 2018 (also EU policies and measures);
- **With additional measures – moderate WAM(DU)**: additional measures supporting public transport and non-motor means of transport and contributing to slower growth of freight transport, moderate increase of load factors, stronger shift towards alternative technologies in transport, higher share of biofuels and use of synthetic fuels, high efficiency improvement;

**With additional measures – ambitious WAMa(DUA)**: very strong support to non-motor means of transport and also implementation of measures that reduce passenger needs for traveling, high increase of load factors, very strong shift towards alternative fuels, high share of biofuels and complete substitution of fossil fuels with synthetic ones, very high efficiency improvement.

### 2.2.4 Model structure

*Methodology*

REES transport model can be classified as:

- bottom up;
- long term;
- sectoral model;
- single node;
- space resolution – Slovenia, but considering also transport activity of foreign vehicles through Slovenia and its effect on energy balance;
- time resolution 2020-2050 with 5-year steps, Backward modelling done for the period 2005-2017 on a yearly basis;
- simulation;
- linear programming.

Model has been developed in excel environment and in the MESAP environment. Excel environment has been used for initial development and testing of the model and scenario assumptions, while final version of the model has been prepared in the MESAP environment.

Vehicle fleet model is based on a detailed vintage stock model that distinguishes the age of the vehicle stock. Separate model is run for each vehicle type and technology (Figure 15). Based on the life expectancy curves vehicles are taken out of use and comparison of number of all vehicles per type and remained vehicles determines number of first-time registered vehicles which are distributed per age of vehicle in line with the defined distribution. Structure of first-time registered vehicles is defined based on the scenarios that have been described in the previous chapter. Outputs from the vehicle fleet models are: share of different technologies per vehicle type, specific energy consumption per technology and type, emission factors per vehicle technology and type. Scenario assumptions for the structure of first-time registered vehicles are checked if they are aligned with the CO2 targets for newly purchased vehicles. Overall 44 technologies are modelled in the vehicle fleet models. Since we do not have data on foreign vehicles it is assumed that they have the same characteristics as domestic vehicles, only structure of the technology is a bit different. Energy efficiency of vehicles changes with change of technology but in the model, it is also assumed that all technologies improve over time. Improvement of technologies has been determined based on the factors that have been provided by the Slovenian Faculty of Mechanical Engineering and company Elaphe.

The main REES Transport model calculates based on transport activity from the PRIMOS model, output from the Vehicle fleet models and other input parameters energy consumption per different vehicle types and carriers and prepares data for emission calculations that are done in the second step. REES Transport model also provides data for the economic evaluation

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of the policies and measures being considered in different scenarios. REES Transport model has two submodules – passenger transport submodule and freight transport submodule.

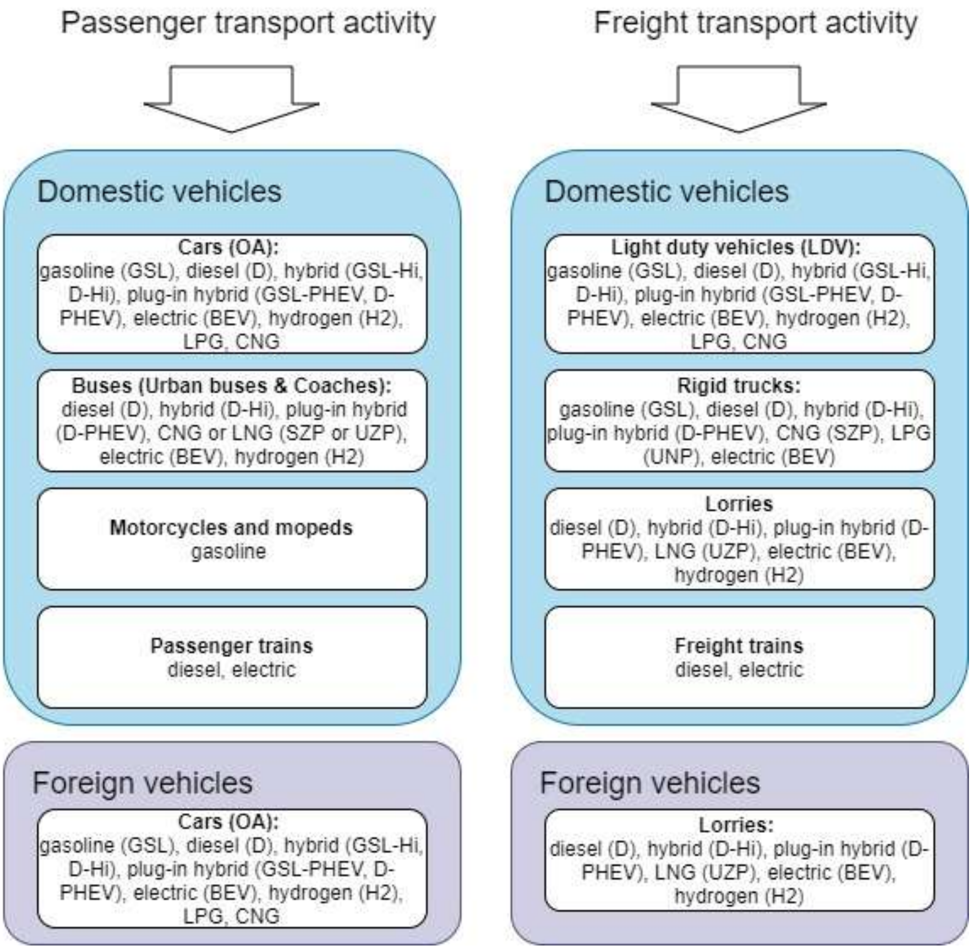

**Figure 15: Level of technological detail in the REES Transport model**

### *Technologies, sectors, processes*

Detailed description of the modelled technologies that were presented in the previous chapter and their characteristics is provided in this chapter.

As is presented in the Figure 15 passengers in the REES Transport model can use the following technologies to move:

- Personal cars (10 technologies)
- Buses (5 technologies for Urban buses and 6 technologies for Coaches)
- Motorcycles and mopeds and (1 generic technology)
- Passenger trains (2 generic technologies)

while freight is can use the following technologies:

- Light duty vehicles (10 technologies)

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- Rigid trucks (7 technologies)
- Lorries (6 technologies)
- Freight trains (2 generic technologies)

Personal cars are by far the most used technology for passenger transport in Slovenia. In 2017 average age of personal car was 9.8 years and it is increasing.

In Slovenia used cars represent an important part of the first-time registered vehicles. That is why we have used different form of life expectancy curve as is normally used in vintage stock models for vehicles. Instead of curve that represents share of vehicles compared to the number of new vehicles (Figure 16 – right), we have used share of vehicles remaining in use compared to the previous year (Figure 16 – left). By using this type of life expectancy curve, we have made possible to consider used vehicles in the model. Used vehicles come into the model through distribution of first-time registrations. Life expectancy curves used for different technologies of passenger cars are presented in Figure 16 while distributions for first time registered vehicles are presented in Figure 18. Shape of curves have been defined by analysis of past data. They represent an average of the past life expectancy curves for the period 2006-2017. Since quality past data were not available for all technologies, it was assumed that life expectancy curves for gasoline cars can also be used for gasoline hybrid, gasoline plug in hybrid, LPG, CNG, BEV (Battery Electric Vehicles) and H2 cars, while life expectancy curves for diesel cars have also been used for diesel hybrid and diesel plug in hybrid cars. As can be seen diesel cars have a bit longer life expectancy than gasoline cars. Life expectancy curves do not change between scenarios only in the ambitious scenario after 2040 OA-B faster and OA-D faster for gasoline and diesel cars have been used to speed up change of fossil fuel-based vehicles. Life expectancy curves for other types of vehicles is shown in Figure 17, while distribution of first-time registered vehicles in right part of Figure 18.

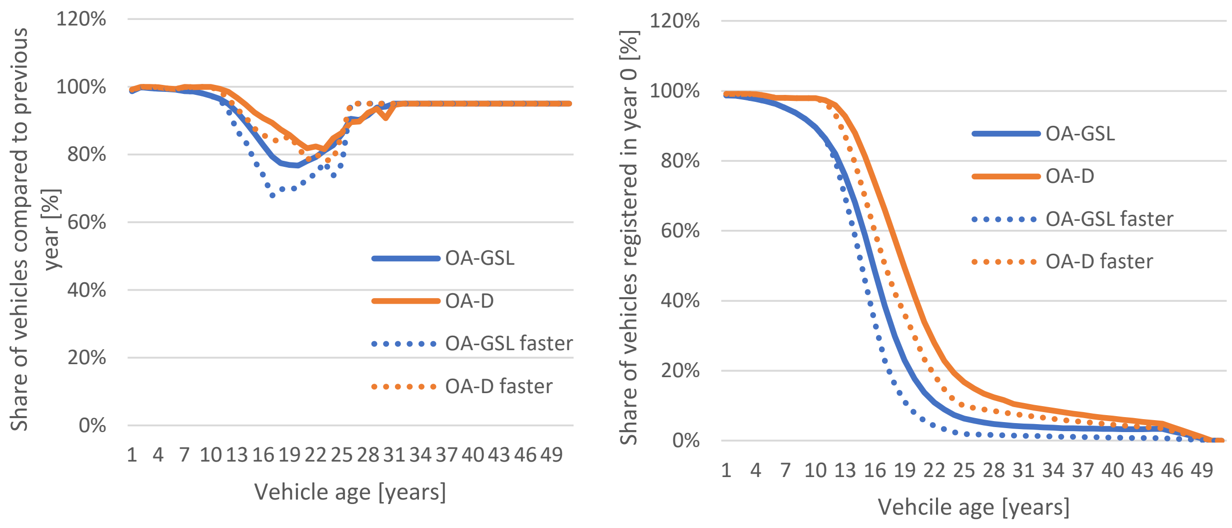

**Figure 16: Life expectancy curves for personal cars – (OA-GSL: gasoline; OA-D; diesel)**

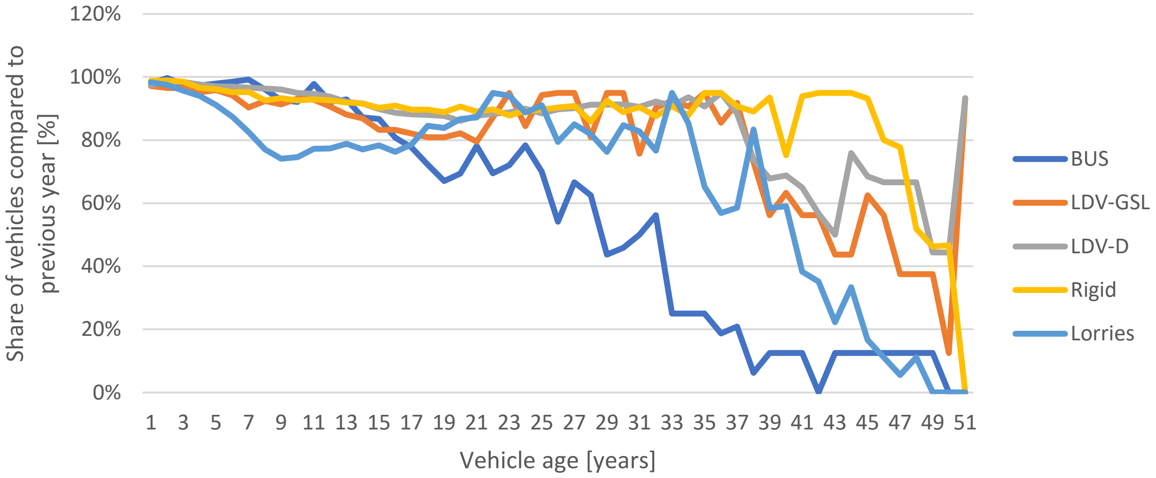

Figure 17: Life expectancy curves for buses, light duty vehicles (LDV), rigid trucks and lorries

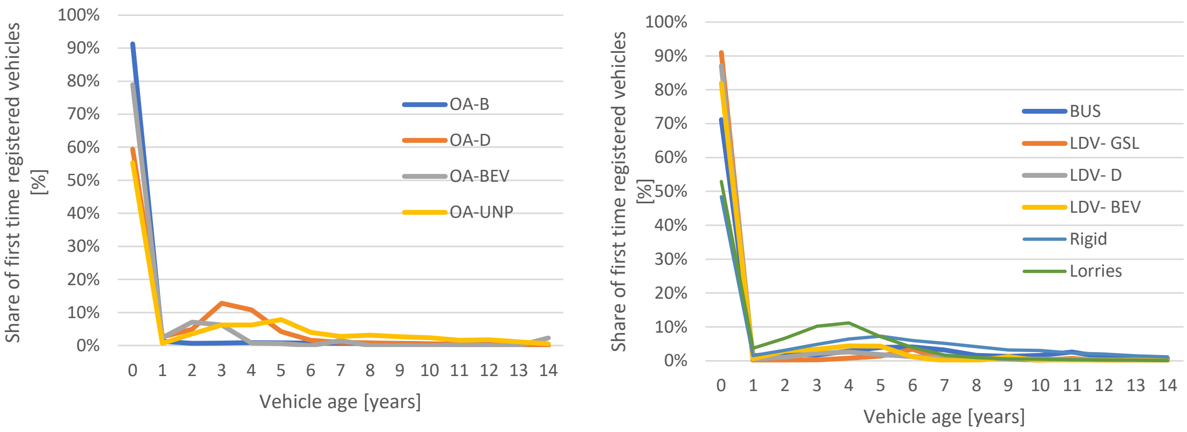

Figure 18: Distribution of first-time registered vehicles for personal cars (left) and other vehicles (right)

Structure of first-time registrations is the main policy parameter that has effect on structure of all vehicles therefore large differences can be seen for this parameter between different scenarios. Projection of structure for different scenario was based on analysis of past development, analysis of different studies and input from company Elaphe. Assumptions for different scenarios for chosen years are presented in the tables below for different types of vehicles (Tab. 9, Tab. 10, Tab. 11, Tab. 12).

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**Tab. 9: Structure of first time registered personal cars for different scenarios in years 2017, 2030 and 2050**

| | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| OA-GSL | 37% | 25% | 12% | 0% | 0% | 0% | 0% |
| OA-GSL Hi | 1% | 35% | 27% | 12% | 17% | 0% | 0% |
| OA-GSL PHEV | 0% | 6% | 25% | 22% | 22% | 4% | 0% |
| OA-D | 60% | 17% | 8% | 0% | 0% | 0% | 0% |
| OA-D Hi | 0% | 6% | 4% | 2% | 4% | 0% | 0% |
| OA-D PHEV | 0% | 1% | 4% | 3% | 5% | 1% | 0% |
| OA-LPG | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| OA-CNG | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| OA-BEV | 0% | 7% | 19% | 58% | 41% | 88% | 80% |
| OA-H2 | 0% | 2% | 1% | 2% | 10% | 7% | 20% |
| Sum of electric vehicles (BEV, PHEV, H2) | 1% | 17% | 48% | 85% | 78% | 100% | 100% |

**Tab. 10: Structure of first-time registered buses for different scenarios in years 2017, 2030 and 2050**

| | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Urban-D | 37% | 26% | 10% | 0% | 5% | 0% | 0% |
| Urban-D Hi | 0% | 3% | 15% | 10% | 7% | 2% | 0% |
| Urban-D PHEV | 0% | 3% | 5% | 10% | 7% | 2% | 2% |
| Urban-CNG | 0% | 15% | 10% | 15% | 14% | 5% | 2% |
| Urban-BEV | 0% | 5% | 10% | 15% | 14% | 38% | 43% |
| Coach-D | 63% | 49% | 44% | 36% | 54% | 11% | 0% |
| Coach-D Hi | 0% | 0% | 3% | 5% | 0% | 5% | 3% |
| Coach-D PHEV | 0% | 0% | 0% | 1% | 0% | 0% | 3% |
| Coach-LNG | 0% | 0% | 5% | 7% | 0% | 37% | 41% |
| Coach-BEV | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Coach-H2 | 0% | 0% | 0% | 0% | 0% | 0% | 5% |
| Sum of electric vehicles (BEV, PHEV, H2) | 0% | 8% | 15% | 26% | 21% | 40% | 54% |

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**Tab. 11: Structure of first-time registered light duty vehicles for different scenarios in years 2017, 2030 and 2050**

| | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| LDV-GSL | 3% | 1% | 1% | 0% | 0% | 0% | 0% |
| LDV-GSL Hi | 0% | 1% | 1% | 1% | 2% | 1% | 0% |
| LDV-GSL PHEV | 0% | 0% | 0% | 1% | 0% | 1% | 0% |
| LDV-D | 95% | 43% | 40% | 11% | 0% | 0% | 0% |
| LDV-D Hi | 0% | 43% | 40% | 26% | 63% | 17% | 0% |
| LDV-D PHEV | 0% | 5% | 8% | 29% | 12% | 21% | 0% |
| LDV-LPG | 1% | 1% | 1% | 1% | 0% | 1% | 0% |
| LDV-CNG | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| LDV-BEV | 0% | 5% | 9% | 29% | 18% | 50% | 85% |
| LDV-H2 | 0% | 0% | 0% | 2% | 5% | 10% | 15% |
| Sum of electric vehicles (BEV, PHEV, H2) | 0% | 10% | 17% | 61% | 35% | 82% | 100% |

**Tab. 12: Structure of first time registered heavy-duty vehicles (rigid and lorries) for different scenarios in years 2017, 2030 and 2050**

| | 2017 | 2030 | | | 2050 | | |
|---|---|---|---|---|---|---|---|
| | | WEM(OU) | WAM(DU) | WAMa(DUA) | WEM(OU) | WAM(DU) | WAMa(DUA) |
| Rigid-D | 36% | 22% | 20% | 18% | 9% | 0% | 0% |
| Rigid -D Hi | 0% | 3% | 3% | 3% | 3% | 1% | 0% |
| Rigid -D PHEV | 0% | 2% | 2% | 5% | 7% | 12% | 0% |
| Rigid -CNG | 0% | 1% | 2% | 2% | 0% | 5% | 6% |
| Rigid -LPG | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Rigid -B | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Rigid -BEV | 0% | 1% | 1% | 3% | 3% | 6% | 23% |
| Lorries-D | 64% | 65% | 59% | 47% | 58% | 0% | 0% |
| Lorries-D Hi | 0% | 2% | 2% | 2% | 15% | 8% | 0% |
| Lorries-D PHEV | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Lorries-LNG | 0% | 4% | 11% | 17% | 4% | 53% | 50% |
| Lorries-BEV | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Lorries-H2 | 0% | 0% | 0% | 3% | 0% | 15% | 22% |
| Sum of electric vehicles (BEV, PHEV, H2) | 0% | 4% | 4% | 11% | 10% | 34% | 44% |

The model also assumes that available technologies improve over time as a consequence of technological improvement of different parts of vehicles. This is considered by decreasing

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specific energy consumption (MJ/km) of different technologies over years. Specific energy consumption is attributed to the year of registration of vehicle. Assumptions regarding these parameters per different technologies are shown in the tables below.

**Tab. 13: Specific energy consumption for personal cars per technology in different scenarios for selected years**

| | | | WEM(OU) | | WAM(DU) | | WAMa(DUA) | |
|---|---|---|---|---|---|---|---|---|
| | Unit | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| OA-GSL | [MJ/km] | 2.24 | 1.98 | 1.79 | 1.73 | 1.34 | 1.34 | 1.34 |
| OA-GSL Hi | [MJ/km] | 1.89 | 1.68 | 1.51 | 1.46 | 1.13 | 1.13 | 1.13 |
| OA-GSL PHEV | [MJ/km] | 1.85 | 1.60 | 1.57 | 1.36 | 1.25 | 1.36 | 1.25 |
| OA-D | [MJ/km] | 2.27 | 2.07 | 1.93 | 1.88 | 1.59 | 1.59 | 1.59 |
| OA-D Hi | [MJ/km] | 2.38 | 2.18 | 2.02 | 1.98 | 1.67 | 1.67 | 1.67 |
| OA-D PHEV | [MJ/km] | 2.05 | 1.84 | 1.80 | 1.56 | 1.44 | 1.56 | 1.44 |
| OA-BEV | [MJ/km] | 0.50 | 0.57 | 0.43 | 0.57 | 0.43 | 0.57 | 0.43 |
| OA-LPG | [MJ/km] | 3.29 | 2.92 | 2.63 | 2.64 | 2.14 | 2.14 | 2.14 |
| OA-CNG | [MJ/km] | 2.46 | 2.18 | 1.97 | 1.98 | 1.60 | 1.60 | 1.60 |
| OA-H2 | [MJ/km] | 0.89 | 0.74 | 0.63 | 0.74 | 0.63 | 0.74 | 0.63 |

**Tab. 14: Specific energy consumption for buses (Urban and Coaches) per technology in different scenarios for selected years**

| | | | WEM(OU) | | WAM(DU) | | WAMa(DUA) | |
|---|---|---|---|---|---|---|---|---|
| | Unit | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Urban-D | [MJ/km] | 13,77 | 13,36 | 12,39 | 13,08 | 11,02 | 13,08 | 11,02 |
| Urban-D Hi | [MJ/km] | 11,70 | 11,35 | 10,53 | 11,12 | 9,36 | 11,12 | 9,36 |
| Urban-D PHEV | [MJ/km] | 6,89 | 6,68 | 6,20 | 6,54 | 5,51 | 6,54 | 5,51 |
| Urban-CNG | [MJ/km] | 22,78 | 19,37 | 19,37 | 19,37 | 18,23 | 19,37 | 18,23 |
| Urban-BEV | [MJ/km] | 7,20 | 6,98 | 6,48 | 6,84 | 5,76 | 6,84 | 5,76 |
| Coach-D | [MJ/km] | 11,30 | 11,06 | 10,48 | 10,72 | 9,32 | 10,72 | 9,32 |
| Coach-D Hi | [MJ/km] | 9,61 | 9,41 | 8,91 | 9,11 | 7,92 | 9,11 | 7,92 |
| Coach-D PHEV | [MJ/km] | 7,91 | 7,75 | 7,34 | 7,50 | 6,52 | 7,50 | 6,52 |
| Coach-LNG | [MJ/km] | 11,30 | 11,06 | 10,48 | 10,72 | 9,32 | 10,72 | 9,32 |
| Coach-BEV | [MJ/km] | 5,02 | 4,92 | 4,66 | 4,76 | 4,14 | 4,76 | 4,14 |
| Coach-H2 | [MJ/km] | 7,91 | 7,75 | 7,34 | 7,50 | 6,52 | 7,50 | 6,52 |

**Tab. 15: Specific energy consumption for light duty vehicles per technology in different scenarios for selected years**

|  |  |  | WEM(OU) |  | WAM(DU) |  | WAMa(DUA) |  |
|---|---|---|---|---|---|---|---|---|
|  | Unit | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| LDV-GSL | [MJ/km] | 3,38 | 3,11 | 2,81 | 2,87 | 2,73 | 2,87 | 2,73 |
| LDV-GSL Hi | [MJ/km] | 3,04 | 2,80 | 2,53 | 2,59 | 2,46 | 2,59 | 2,46 |
| LDV-GSL PHEV | [MJ/km] | 2,37 | 2,18 | 1,96 | 2,01 | 1,91 | 2,01 | 1,91 |
| LDV-D | [MJ/km] | 2,50 | 2,30 | 2,08 | 2,13 | 2,02 | 2,13 | 2,02 |
| LDV-D Hi | [MJ/km] | 2,25 | 2,07 | 1,87 | 1,92 | 1,82 | 1,92 | 1,82 |
| LDV-D PHEV | [MJ/km] | 1,75 | 1,61 | 1,45 | 1,49 | 1,42 | 1,49 | 1,42 |
| LDV-BEV | [MJ/km] | 0,89 | 0,85 | 0,79 | 0,85 | 0,79 | 0,85 | 0,79 |
| LDV-LPG | [MJ/km] | 3,38 | 3,11 | 2,81 | 2,87 | 2,73 | 2,87 | 2,73 |
| LDV-CNG | [MJ/km] | 2,50 | 2,30 | 2,08 | 2,13 | 2,02 | 2,13 | 2,02 |
| LDV-H2 | [MJ/km] | 1,11 | 1,11 | 1,01 | 1,11 | 1,01 | 1,11 | 1,01 |

**Tab. 16: Specific energy consumption for personal heavy-duty vehicles (Rigid and lorries) per technology in different scenarios for selected years**

|  |  |  | WEM(OU) |  | WAM(DU) |  | WAMa(DUA) |  |
|---|---|---|---|---|---|---|---|---|
|  | Unit | 2017 | 2030 | 2050 | 2030 | 2050 | 2030 | 2050 |
| Rigid-D | [MJ/km] | 7,53 | 6,80 | 6,16 | 6,34 | 5,48 | 6,34 | 5,48 |
| Rigid -D Hi | [MJ/km] | 7,08 | 6,69 | 5,92 | 6,21 | 5,19 | 6,21 | 5,19 |
| Rigid -D PHEV | [MJ/km] | 6,70 | 6,35 | 5,65 | 5,91 | 4,98 | 5,91 | 4,98 |
| Rigid -CNG | [MJ/km] | 9,03 | 8,12 | 7,11 | 7,56 | 6,24 | 7,56 | 6,24 |
| Rigid -LPG | [MJ/km] | 7,97 | 7,17 | 6,38 | 6,38 | 5,98 | 6,38 | 5,98 |
| Rigid -GSL | [MJ/km] | 6,93 | 6,24 | 5,54 | 5,54 | 5,20 | 5,54 | 5,20 |
| Rigid -BEV | [MJ/km] | 3,29 | 3,26 | 3,18 | 3,14 | 3,04 | 3,14 | 3,04 |
| Lorries-D | [MJ/km] | 12,17 | 10,99 | 9,96 | 10,25 | 8,85 | 10,25 | 8,85 |
| Lorries-D Hi | [MJ/km] | 11,45 | 10,82 | 9,57 | 10,05 | 8,40 | 10,05 | 8,40 |
| Lorries-D PHEV | [MJ/km] | 10,84 | 10,26 | 9,13 | 9,55 | 8,05 | 9,55 | 8,05 |
| Lorries-LNG | [MJ/km] | 14,61 | 13,13 | 11,50 | 12,22 | 10,09 | 12,22 | 10,09 |
| Lorries-BEV | [MJ/km] | 5,31 | 5,27 | 5,15 | 5,08 | 4,92 | 5,08 | 4,92 |
| Lorries-H2 | [MJ/km] | 9,69 | 9,23 | 8,21 | 8,65 | 7,39 | 8,65 | 7,39 |

For PHEV specific energy consumption covers both fossil fuel and electricity. The model uses different estimates regarding the share of fossil fuel use per vehicles type. The share does not change over time, only for personal cars minor increase has been assumed, due to the fact that those drivers that prefer electricity would opt for BEV instead of PHEV, since by 2050 there would be no obstacle regarding availability of different types of BEV, while for heavy duty vehicles slight decrease is anticipated.

**Tab. 17: Share of fossil fuel consumption in specific fuel consumption for PHEV**

| | Unit | 2017 | 2030 | 2050 |
|---|---|---|---|---|
| OA-GSL PHEV FF | [%] | 77% | 77% | 81% |
| OA-D PHEV FF | [%] | 77% | 79% | 80% |
| Urban-D PHEV FF | [%] | 50% | | |
| Coach-D PHEV FF | [%] | 60% | | |
| LDV-GSL PHEV FF | [%] | 77% | | |
| LDV-D PHEV FF | [%] | 77% | | |
| Rigid -D PHEV FF | [%] | 95% | 95% | 94% |
| Lorries -D PHEV FF | [%] | 95% | 95% | 94% |

For motorcycles and moped specific consumption has been constant over the whole modelled period, being 1.24 MJ/km.

Emission factors used in the Emission model have been determined using COPERT 5[3] model for road transport vehicles and Inventory reports[4] for other modes of transport. For non-exhaust emissions factors from 2019 EEA guidelines have been used.

### *Connections with other models*

REES Transport model uses transport activity as an input, which is taken from the PRIMOS model. Since PRIMOS model calculates transport activity on average working day this is not directly usable in REES transport model, which uses yearly transport activity as an input. Based on various analysis it has been concluded that growth rates of transport activity per average working day are very well aligned with growth rates of yearly transport activity. Therefore, PRIMOS growth rates have been applied to the REES transport model.

To be able to apply growth rates from PRIMOS model, we first had to estimate yearly transport activity in the base year (2017) which was, due to incomplete transport statistics in Slovenia, a difficult task. Transport activity for domestic vehicles was estimated on the basis of the data from Statistical Office (pkm for passenger public transport, tkm for domestic heavy duty vehicles and trains; driven kilometres for domestic vehicles, survey data on mobility in Slovenia) and Environmental Agency of Slovenia (output from the COPERT model), but due to importance of effect of foreign vehicles on fuel sold in Slovenia also transport activity of foreign vehicles driving through Slovenia had to be assessed. This was especially difficult due to lack of data. For the estimation data on road usage and return of excise duty for heavy duty vehicles was used.

The structure of different modes of transport from the PRIMOS model was directly used in the REES transport model.

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[3] COPERT 5.2.2 version has been used

[4] National inventory report (**https://unfccc.int/documents/273460**); Informative Inventory report (https://webdab01.umweltbundesamt.at/download/submissions2021/SI_IIR2021.zip?cgiproxy_skip=1)

*Future development of the model and research challenges*

Future model development will go in different ways:

6. **Better connection between sectors**: Electric vehicles are now from the perspective of energy grid seen as a consumer of electricity but in the future, it will be necessary to understand the role of electric vehicles also as an energy storage especially when it comes to electricity production from PV plants there are installed in households and service sector, places where cars are parked most of the time – for that more detailed spatial and time resolution is needed in the model
7. **Better modelling of effect** of measures on model parameters **– connection between measures/instrument and model parameters**: Implementation of different decision models in the REES Transport model, Better integration of measures effecting price of fuels and vehicle ownership in the model
8. **Use of other environment** for the development of the model – e.g. Python to enable more flexible development allowing faster update of the model and faster preparation of different scenarios and better-quality management
9. **Better integration between cost model and REES Transport model** that will enable faster estimation of costs of different measures since a lot of the data needed in the cost model, will also be needed in the decision models, that will be developed
10. **Better integration between PRIMOS model and REES Transport model**, so that results from the REES model will also be used when preparing scenarios for the PRIMOS model.

### 2.2.5 Model results

In this chapter some of the results from the REES Transport model are presented.

Average CO2 emissions of new cars are an interesting result, since they show the level of ambition of different scenarios. Numbers on the graph show real emissions not type approved, that is why in 2015 they are approximately 40 % higher compared to type approved values. For 2021 the target value is 95 gCO2/km which is not achieved although in reality it was achieved by majority of producers due to super credits for electric vehicles. Average CO2 emissions decrease in all scenarios, In WEM(OU) scenario they are 24 % lower in 2030 compared to 2020, in WAM(DU) scenario they are 43 % lower while in WAMa(DUA) scenario they are 74 % lower. In 2050 emissions are 67 %, 98 % and 100 % lower respectively. The main reason for higher decrease in more ambitious scenarios is higher share of electric vehicles. Specific CO2 emissions for new personal cars in different scenarios are presented in the figure below.

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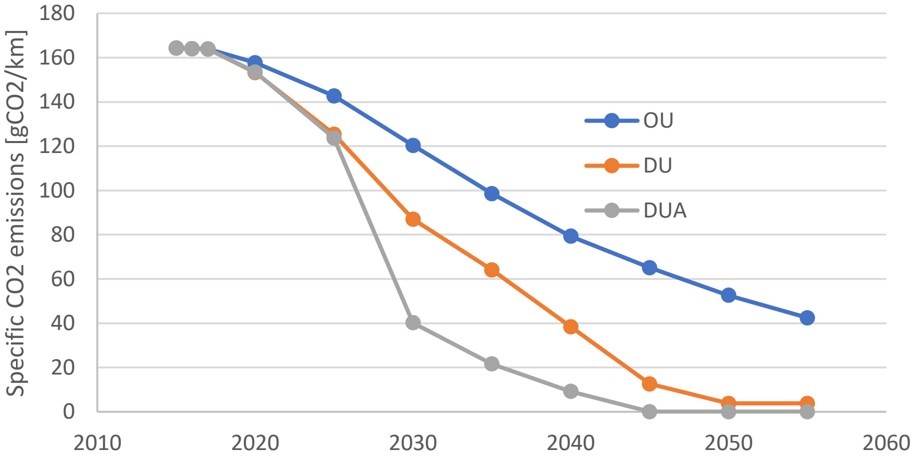

**Figure 19: Specific CO2 emissions for new personal cars in different scenarios**

Energy consumption in WEM(OU) scenario increases by 2030 compared to 2017. The majority of energy is still represented by diesel fuel. By 2050 energy use slightly decreases but stays above 2017 levels. In WAM(DU) and WAMa(DUA) scenario energy in 2050 falls well below 2017 levels and large changes in structure of fuels is observed. In WAMa(DUA) scenario energy use in 2050 is 48 % below 2017 levels, with almost all decrease happening after 2030. Electricity and synthetic gas being are the most important fuels in 2050. Electricity is mainly used in passenger transport and synthetic gas in freight transport. Total energy consumption in transport per fuel for different scenarios and selected years is presented in the figure below.

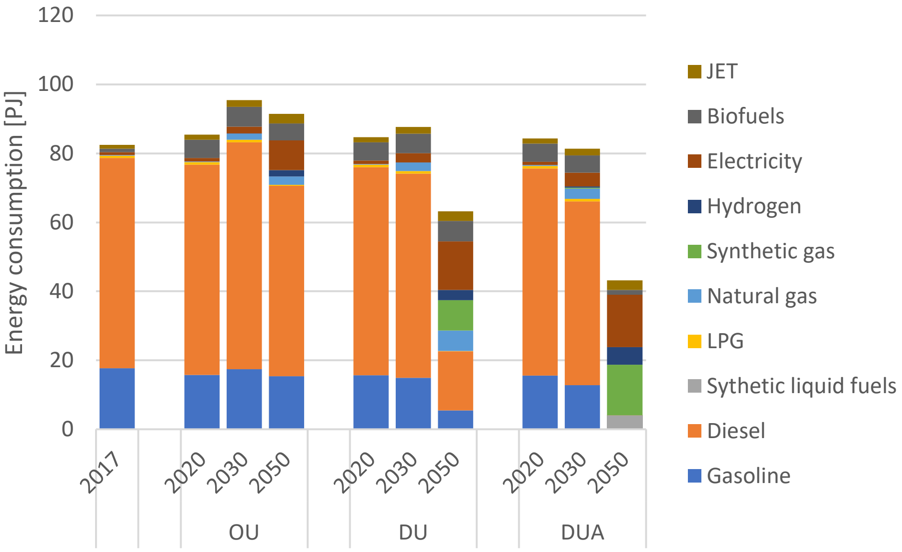

**Figure 20: Total energy consumption in transport per fuel for different scenarios and selected years**

GHG emissions are strongly correlated with energy consumption but use of low carbon or carbon free fuels can have important impact on reduction of emissions. Use of biofuels, electricity and carbon neutral synthetic fuels decreases GHG emissions contributing to 99 % reduction in WAMa(DUA) scenario compared to 2005.

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Air pollutant emissions decrease faster than GHG due to implementation of EURO standards and use of technical equipment for exhaust gas cleaning. Towards 2050 additional reductions are due to electrification of the transport sector (especially passenger transport).

Figure below presents the GHG emissions (left) and NOx emissions (right) per type of vehicles.

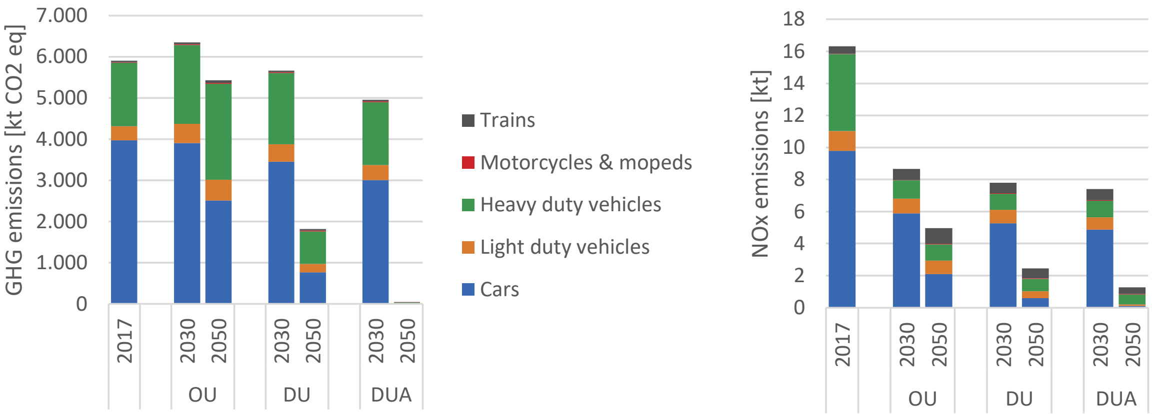

**Figure 21: GHG emissions (left) and NOx emissions (right) per type of vehicles**

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## 2.3 Transport activity model PRIMOS

### 2.3.1 Purpose of the model

Basic characteristics of this world are totality, constant changing and relativity of space and time. Everything is in constant motion. The natural flow of things is holistic and comprehensive. World is essentially an indivisible whole. In reality everything affects everything else. For there is always a force field that connects whole reality in one settled entirety causing motion and dynamic balance at the same time. Such are the laws of this world.

In both, macroscopic and microscopic world, there are elements and interactions among them. At the level of human relations, physical interactions are generally understood as traffic. In today's society, in spite of huge development of electronic communications, there is still a great need for transport, i.e. spatial mobility of larger proportions. That is so because it makes satisfying the basic human life and social needs possible. In the past specialization placed many activities that represent these needs somewhere else, away from people’s homes.

Transport is an integral part of the world so it also depends on its fundamental laws. It is also characterized by dynamic and constant changing, but at the same time it is one of the factors which connect parts in a whole.

The current generally accepted way of life requires passenger and cargo transport. The first one is carried out for a number of purposes, the other one for various types of goods. All this has important effects on development, including the development of Slovenia. The level of development is measured by various indicators, covering cultural, social, health, environmental, economic and other aspects. Transport affects all of them, both positively and negatively.

Transport has many positive and negative impacts. Among the negative impacts are clearly the ones on the environment. Transport in fulfilling its basic activities also leads to a greater or lesser environmental pollution. Excessive noise, air pollution, contribution to climate changes, land use, degradation of the natural and built-up areas, etc. stand out particularly in this.

Transport is an integral part of life. However, it can boost or hinder development. Development in this case is meant to be an evolution in a positive direction, i.e. to greater economic growth, to more equal opportunities for all, to greater freedom, decrease of effects on environment, improved security, greater harmony, better health, etc. Transport may therefore contribute to a greater development of the country, but may also slow it down or halt it – depending on how it is regulated.

Transport measures is generally expensive and have long term consequences. Therefore, before the realization it is worth examining how to solve existing and anticipated problems and what would be the impacts of the proposed measures.

The expected effects should be measured in advance. The basis of each measurement practice it is a relevant theory – and any theory is a model, a simplified picture of reality. Using mathematical equations, i.e. models, it is possible to express the many laws which govern this world. These serve to understand the current situation as well as to predict the coming events.

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Modelling it is a complex and multifaceted activity. The purpose of studying systems using models is to find a variety of effects without experimenting on a real object. In cases where the considered system does not yet exist in real, modelling is the only option.

There are several types of models. Transport models are among the mathematical models, which were initially of deterministic nature. Since the traffic at a more detailed level is a random phenomenon, the stochastic transport models that are closer to the real phenomena are in use recently. Like many others, also the transport models were developed in order to allow the measures envisaged could be previously tested to determine if they bring the expected and desired effects and improvements of the situation or not. It is whether they point to the direction of development and are in economical limits or not.

Existing national transport model was upgraded in order to enable modelling of CO2 emissions, testing different scenarios of transport policies and prepare scenarios for 2030 and 2050.

### 2.3.2 Model Inputs

#### *External influencing factors*

The economic development is measured by various indicators. One of the more established ones is the growth of gross domestic product. It is concluded that there is a close correlation between growth in gross domestic product and increase in traffic. This interdependence has been proven in many various environments and is quite obvious. The impact is mutual. Growth in gross domestic product effects on traffic growth and traffic growth affects the growth of gross domestic product.

For freight transport, this represents a part of the production and marketing process. Transport of raw materials, semi-finished and finished goods distribution is a part this process. Therefore, the growth of gross domestic product and growth of freight transport are closely correlated. The rapid growth of gross domestic product requires rapid growth of freight traffic and vice versa. Rapid growth of freight transport shows the rapid growth in gross domestic product, as the growth of freight transport facilitates and encourages production.

For passenger traffic greater gross domestic product causes the availability of bigger funds for personal consumption, which results in more (especially non-working) trips. Passenger traffic growth accelerates consumption, which in turn increases production.

In addition, the growth in gross domestic product is related to the mere construction of transport infrastructure.

#### *Internal Input Parameters*

Many factors influence how, where and when people travel:

- demographic structure of the population of Slovenia and its visitors,
- location of houses, jobs, schools and services,
- level of motorization,
- extent and quality of road network,
- availability and attractiveness of public transport,

- other.

In addition to those the freight transport, which varies in time, is affected by the economic situation, the costs of goods distribution, traffic jams, etc.

The accuracy level of each model therefore also depends on the availability and relevance of data. One of the major segments of the preparation of transport model is a high-quality data collection. These are needed both for the present situation and the future development. The basis for the current status data is the existing databases and current surveys, whilst current projections and planning documents represent the basis for the future state.

The use of transport model can be quite universal, but only if its capabilities have actually been used. Therefore, the interested participles need to be aware of these opportunities. Since it's a national model with elements of regional models, interested participles are mainly represented by the government, as the regions have not yet formally been established. There are two main participles: The Ministry of Infrastructure and Ministry of the Environment and Spatial Planning with its directorates, agencies and companies.

Mobility rate (i.e. number of trips per person per day) represents a general indicator of living standards and development of the country or region concerned. More developed countries that have higher standards of living, also have higher levels of mobility.

Transport affects also other aspects of life. e.g. the equal or unequal opportunities for education, health care, etc., the greater or lesser dependence or freedom of choice or decision, greater or lower security, better or worse health and human welfare, etc. In addition, an adequate transport service should be provided when needed. We measure this through accessibility and generalized costs (travel time, transport costs).

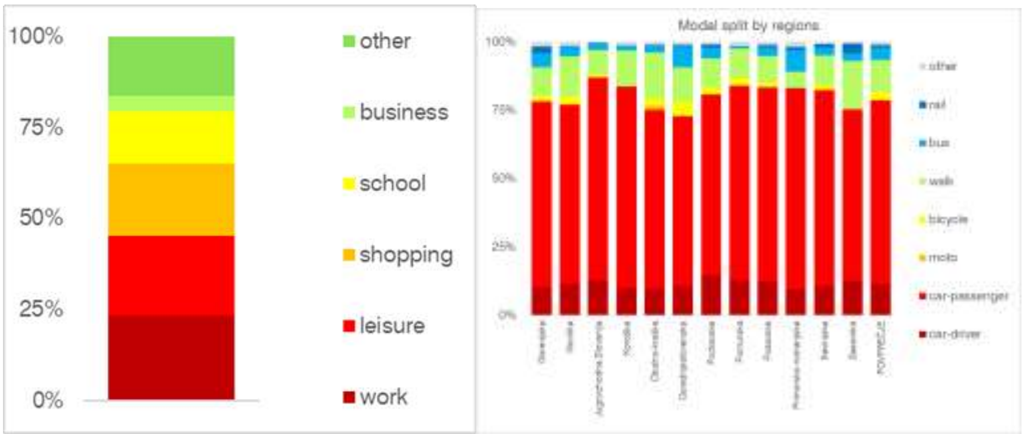

**Figure 22: Mobility patterns (trip purposes – left, modal split by regions – right)**

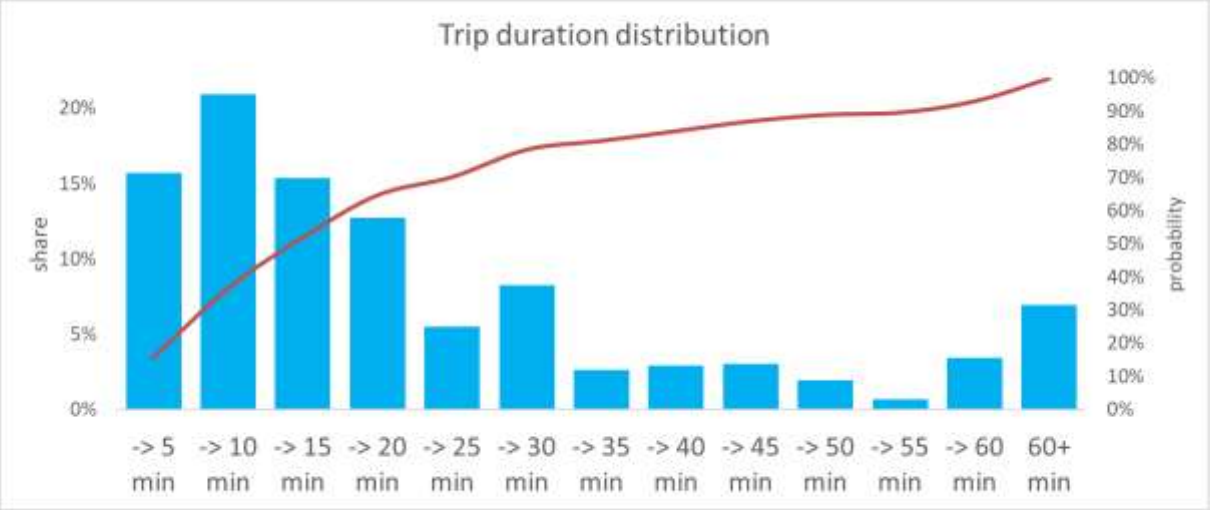

**Figure 23: Mobility patterns (trip duration distribution)**

Last, but not least, very important driver is network development. This is represented through infrastructure projects (new rail and road connections) and transport policy measures (parking policy, internalisation of external costs, public transport services…). These measures were taken from the current transport strategy.

### 2.3.3 Key assumptions, scenarios and border conditions

Key assumptions and border conditions for different scenarios are described in previous chapter. Modelled scenarios are listed below:

- • **Without measures**: assuming transport activity with no measures after 2015; vehicle fleet projection – no changes in structure, slow improvement in efficiency, no alternative fuels
- • **With existing measures:** transport activity projections considering measures from Slovenian transport strategy and transport programme, support measures for alternative technologies slowly shifting structure of vehicles to alternative technologies, moderate improvement of efficiencies and use of biofuels; considering all the measures that have been implemented or adopted before end of 2018 (also EU policies and measures)
- • **With additional measures – moderate**: additional measures supporting public transport and non-motor means of transport and contributing to slower growth of freight transport, moderate increase of load factors, stronger shift towards alternative technologies in transport, higher share of biofuels and use of synthetic fuels, high efficiency improvement

- **With additional measures – ambitious**: very strong support to non-motor means of transport and also implementation of measures that reduce passenger needs for traveling, high increase of load factors, very strong shift towards alternative fuels, high share of biofuels and complete substitution of fossil fuels with synthetic ones and very high efficiency improvement.

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### 2.3.4 Model structure

*Methodology*

In transport models macroscopic, mesoscopic and microscopic models are generally distinguished. Macroscopic or strategic models are wider and more global, i.e. general, but less precise and as the name suggests, mostly suitable for strategic studies. They include the interdependence among settlement, socioeconomic and traffic conditions and at the same time among elements of the transport system itself. They can cover a very large network, which is usually at least partially simplified. All types of passenger and freight traffic divided by the purposes and types of vehicles are to be modelled. Purposes of trips for passenger traffic and types of vehicles as well as types of cargo for freight transport are the basic model-based units. Results are usually presented in the unit of annual average workday traffic, from which traffic volumes per one or more hours can be derived for various means of transport, purposes, etc.

The macroscopic model is the basis for mesoscopic or microscopic model and these two is its upgrade. The usual passenger macroscopic model includes 4 stages:

- production and attraction,
- distribution,
- mode choice and
- assignment.

In four-stage models the first three stages represent a demand model, whilst the final stage represents a model of assignment.

Four-stage models are also called synthetic because the trip-matrices are the results of mathematical models and are not obtained directly from surveys, as in so called direct models.

Strategic models are suitable for strategic assessments.

According to the relevant area and the types of questions to which answers are expected, the models are basically separated into four hierarchical types:

- international models,
- national models,
- regional models and
- local models.

National Transport Model of Slovenia – PRIMOS (*PR*ometni *I*ntegralni *MO*del *S*lovenije) is national model and was used for evaluation of national transport and spatial policies and their consistency, the main national flows and infrastructures, their effects, etc.

*Technologies, sectors, processes*

National Transport Model of Slovenia (PRIMOS) is a national strategic multi-modal model and one of the latest models of this type. The model includes international, national and regional level. Therefore, a hierarchical approach is established, where the model consists of an appropriately developed international model, of a highly (i.e., in detail) developed national model and also of less detailed regional sub-models. The focus is on national level, so the international model only includes the elements that influence the Slovenian area in detail, while the regional sub-models are rougher because the model's national nature. Later it will be necessary to also develop the more detailed regional models.

National Transport Model of Slovenia (hereinafter PRIMOS) involves a direct interdependence between the settlement, socioeconomic and traffic conditions as well as between elements of the transportation system. So, it is a synthetic 4-stage transport model. This applies to both, the so-called internal (national and regional) and the so-called external (international) transport model. It means that the method of traffic growth factors is entirely excluded and thus also the often-connected subjective evaluation. The model is based on an objective basis and clear platforms. So, the outcome of the model in principle doesn't depend on the one that actually works with it.

PRIMOS is a disaggregated simultaneous stochastic transport model with a dynamic character. All levels of the model are mutually interdependent and ultimately balanced. Both passenger and cargo traffic are modelled.

Basic model unit are vehicles or passengers per annual average workday.

Other major features of the model:

- includes the entire Slovenian population and area,
- allows interactive modelling of land use and traffic,
- specifies people's decision on how, where, when and with what means of transport they travel,
- it's a tool for prediction and analysis of the effects of various policies and measures,
- also enables the modelling of the impact of road tolling, congestion charging, charging pollution and/or extra tolling to internalise external costs and to enforce the parking policy (influences on the mode choice, distribution of traffic across the network, etc.),
- integrally includes impacts on the environment (air pollution, noise) and road safety,
- represents a framework for determination of traffic demand on more detailed regional and local level,
- represents a comprehensive database and
- makes a wide range of detailed analysis possible, in particular, transport, economic and environmental.

The outcome of the model allows more detailed analyses:

- detailed traffic analyses,
- mapping of network saturation,
- accessibility analyses,
- demographic and economic analyses and analyses of land use in conjunction with the transport system,
- environmental analyses,

- road safety analyses,
- analyses of economic and financial feasibility of investments,
- more detailed analyses of smaller areas of Slovenia.

The whole working process consists of four elements:

- **modelling** – development, calibration and validation of the model, forecast of future conditions and maintenance of the model,
- **collecting traffic and socioeconomic data** – household surveys, traffic counts on roads and trains, a database for road and rail infrastructure and public transport, statistical data on transport zones,
- **collecting planning data** – data about future land use based on regional plans,
- **involving users** – client and developer of the model have to present it to users and introduce them into the application procedure.

In an advanced society the transport model represents one of the key bases for decision-making on transport and spatial policy, on the investments in the infrastructure demanding time and finances, on the form and dimensions of roads and their impacts, etc. It is therefore important that the model results are reliable.

Reliability and credibility are the key characteristics of good and useful traffic models. The necessary precision of the model is achieved by the calibration, whilst the reliability and credibility required are proved by the validation.

Validation is an obligatory part of a model and the only way to justify its quality. Increasing complexity of models also led to greater complexity of the validation procedures.

Calibration and validation are two very important steps, independent of each other, yet related.

- Calibration is a procedure of more detailed definition of model parameters, so that the model's results would match the observed conditions in the study areas as much as possible.
- Validation is a verification and confirmation of the validity and usability of the calibrated model as well as credibility of its forecasts.

A transport model must adequately reproduce the base year state. This is the necessary condition but not sufficient. Particularly in 4-stage models, a good imitation of the current situation does not mean that the transport model is adequate to provide a credible traffic demand forecast. The model must also be adequately responsive to the system and development changes; only then it is considered to be useful. Thus, there is a close correlation between the use or usability and the validation of a model.

In complex models, such as PRIMOS, two categories of validation checks are therefore required:

- *Validity and relevance check of the model:* it includes a comparison of relations and parameters and model results with the exchanged values of the current situation of the

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analysed area and with potential other sources; model is evaluated regarding the acceptable error rate and the relevance of behaviour within the theoretical and logical laws.

- *Check of the real responsiveness of the model:* it includes responsiveness of the specific elements of the transport system and other components of the model to changes, measured by the elasticity factor; response to changes must be in realistic limits determined on the basis of researches.

Model is a representation of the real world. Despite the growing complexity of transport models, they are still a simplified perception of reality. Therefore, excessive deviations from the reality and errors can occur easily. In the process of development and calibration of the transport model the probability of error is actually high. For example, measurement errors (errors in obtaining and processing of data), errors in survey samples, errors due to incorrect specification of the model (inappropriate model structure, over-simplifications, lack of appropriate variables, etc.), errors in data aggregation, calculation and other errors.

Transport model has four stages and errors can already appear in the stage of production and attraction, usually increase in the distribution and modal split phase and further intensify in the assignment phase. Errors actually accumulate and most strongly express in the assignment phase. As in the phase of network assignment it is difficult to determine the source of an error or errors, it makes sense to also validate the intermediate stages.

If a significant deviation in model outcomes compared to the measured values is already established for the base year, then it is very likely that the deviation in prognostic year will only be greater. It is therefore important for the model to adequately simulate the current situation.

By performing the sensitivity tests, it is possible to ensure that changed conditions would cause the changes in traffic volumes that would be normal according to valid and current behaviour patterns.

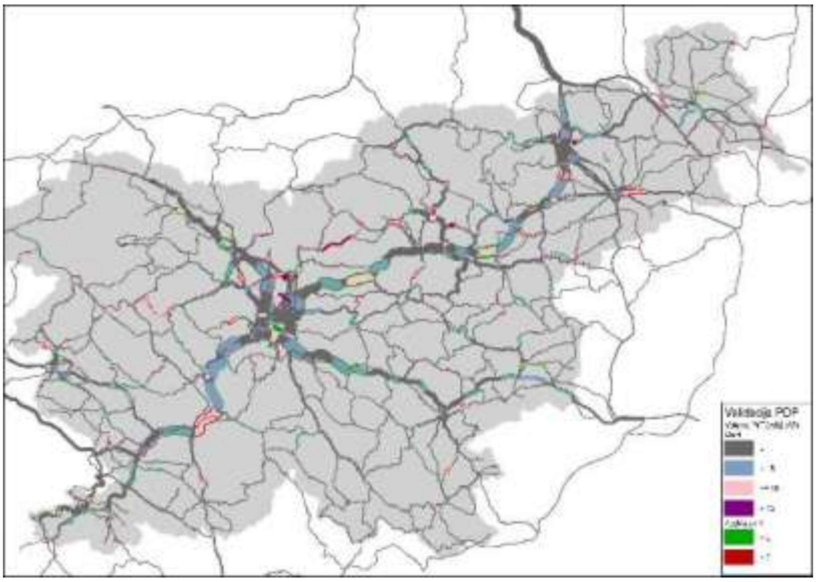

**Figure 24 Validation by sections, all vehicles, average workday, 2008**

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Statistical method GEH is a form of $\chi^2$ test, which includes both absolute and relative errors. In the case of all-day traffic, the value of GEH < 5 is reached on 65% of sections and the value < 8 on 85% of sections. Blue colour represents the value of GEH < 5, bright red the value of GEH from 5 to 10 and dark purple the value of GEH > 10. In the figures it can be seen that high GEH values are not accumulated in any part of the network. This means that the model is spatially balanced and that deviations occur locally. These deviations are largely due to limitations of a strategic model.

**Tab. 18: Sensitivity test**

| means of transport | component | change +/- | elasticity [PC vehicles*km] | [PC | trips by PC | [PT passengers] | recommended value |
|---|---|---|---|---|---|---|---|
|  | travel time | 20% | -0,76 | -1,09 |  |  | <-2 |
|  |  | -20% | -0,68 | -1,02 |  |  |  |
| passenger car | monetary | 20% | -0,35 | -0,40 |  |  | app. -0.4 |
|  |  | -20% | -0,28 | -0,33 |  |  |  |
|  | parking | 20% |  |  | -0,25 |  | -0,1-> -0,4 |
|  |  | -20% |  |  | -0,23 |  |  |
|  | travel time | 20% |  |  |  | -1,93 | <-2 |
| public transport |  | -20% |  |  |  | -1,87 |  |
|  | ticket price | 20% |  |  |  | -0,18 | -0.2->-0.9 |
|  |  | -20% |  |  |  | -0,16 |  |

Reliability of transport models is often brought to attention. We analysed more than 15 different transport studies from past twenty years and established that most of the transport models' projects well within 10-20% for long-term forecast.

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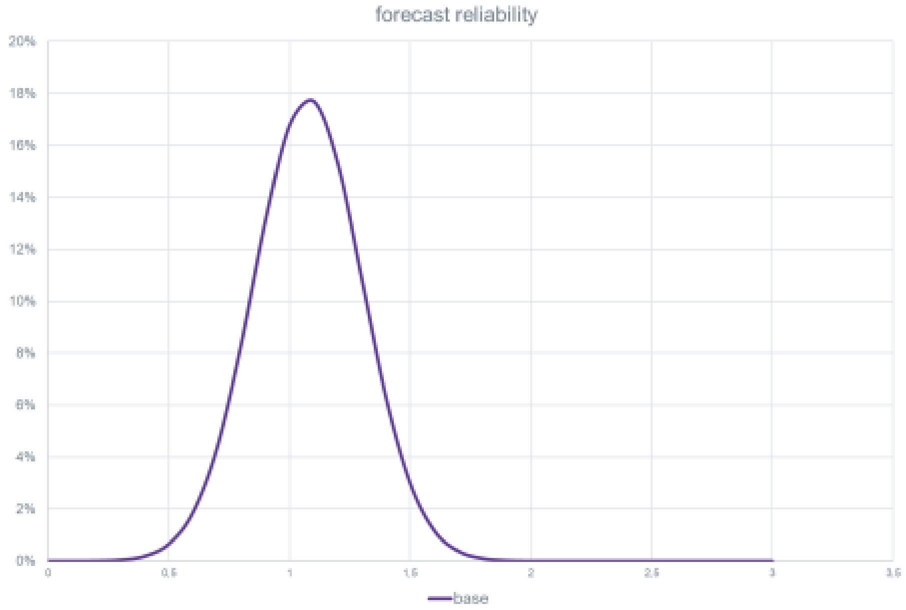

**Figure 25: Average reliability of transport models (concerning forecast)**

*Connections with other models*

Results of transport model, expressed in transport work (passenger kilometres, tonne kilometres by modes and years) are exported to Transport energy demand model described in section *2.3 Transport activity model PRIMOS*.

*Future development of the model and research challenges*

National transport model PRIMOS was updated within Life project. It was extensively used to calculate transport work by modes for different scenarios and modelled years. These results were direct input to other models, mainly modelling of energy consumption and CO2 emissions. Review of methodology in EU shows that such detailed transport modelling for the purpose of climate strategies is relatively rare. It raises significantly the reliability and robustness of the emissions results. As any model, it is sensitive to reliability of input parameters, especially for forecast and simplifications. Main challenge laying ahead of the models are their updates and further use within planning appropriate measures.

### 2.3.5 Model results

The most important results considering projection of emissions is transport work by different scenarios. The graph below shows detailed results of effects of different measures to reduction of GHG.

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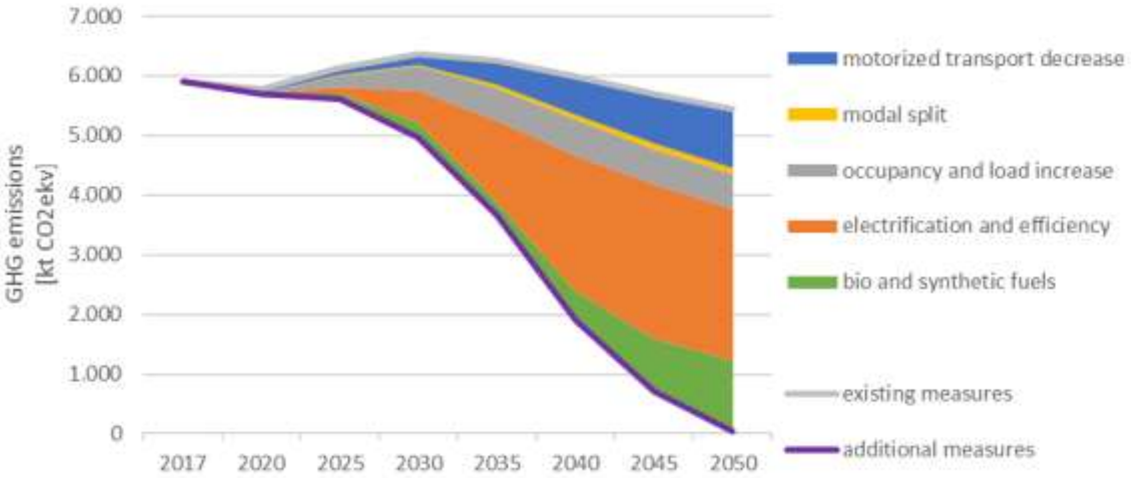

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**Figure 26: Effects of different measures to reduction of GHG emissions**

Results of transport model were used to prepare important climate related strategies such as National Energy and Climate Plan (NECP) and Climate strategy. They were also used to check investments in Action plan for investment 2020-2025.

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## 2.4 Industry

### 2.4.1 Purpose of the model

REES-IND is a main tool for calculating long-term energy balances for the industrial sector and analysing different development strategies. The set of models used in an integrated manner includes, in addition to the REES-IND model, also more detailed simulation or optimization models of individual segments of the energy system. The REES-IND simulation process-technology model enables the simulation and evaluation of the instruments envisaged and their impacts, such as sets of instruments linked in strategies. The computational model connects the effects of various measures with a transparent model presentation, provides consistent assessments and sets the framework for a consistent and uniform approach to the identification of instruments, measures and final effects in different sectors and sub-sectors. Depending on the details of the treatment, the set of models used in an integrated approach requires, depending on the details of the treatment, more detailed simulation, or optimization models of individual energy system segments, which means that the models are interconnected at the input/output level or consider the same assumptions and co-influence the calculations.

REES-IND calculates the prospective energy end-use balances specifically for energy-intensive industries (manufacture of paper and paper products (C17), manufacture of chemicals and chemical products (C20), manufacture of other non-metallic mineral products (C23) and manufacture of basic metals (C24)) and other industries and estimates local electricity production based on the shares of different technologies in the end-use structure and links with influential parameters. The model allows separate treatment of measures for the sector included in the European Emissions Trading Scheme (EU ETS).

### 2.4.2 Model Inputs

*Influencing factors*

Energy use in industry includes energy use in the manufacturing industry, the energy sector, in the extraction of other raw materials and in construction. The range of activities in the 18 sectors (standard classification of activities[5]) is treated based on a physical product indicator, with which energy use for each industry is correlated. For three energy-intensive industries, the volume of the physical product of each industry is determined quantitatively in the form of physical production (C17, C23 and C24 (steel and aluminium)), for C20 and other industries the volume of the physical product is determined by the value of production in monetary units. Data on physical production to date has been used as the leading input parameter of the model for industry (baseline year 2017). The projection was drawn up in accordance with forecasts based on the current development of industrial sectors, the situation in the baseline year 2017 and past trends. Manufacturers' expectations of future trends were also considered, as well as guidelines and trends drawn from professional literature and international studies. For energy-intensive industries, the projections of the physical product in physical units (kt) for the following sectors: C17 - production of paper and paper products, C23 - production of non-metallic mineral products and C24 – production of metals were prepared, excluding sector C20 – the production of chemicals and chemical products, said projections being calculated in monetary units (value-

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[5] An overview of the standard classification of activities is available at http://evem.gov.si/info/skd-seznam/

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added). Other industrial sectors were considered in aggregated form, the leading parameter being added value in monetary units.

**Tab. 19: Main influencing parameters of the REES-IND model by industrial branch**

| **Industry** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **A physical product** | | | | | | | |
| C17 | 2017=1 | 1.00 | 1.02 | 1.03 | 1.05 | 1.06 | 1.08 |
| C23 - cement | 2017=1 | 1.00 | 1.01 | 1.03 | 1.05 | 1.07 | 1.09 |
| C24 | 2017=1 | 1.00 | 1.03 | 1.07 | 1.08 | 1.09 | 1.10 |
| Primary aluminium | 2017=1 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Secondary aluminium | 2017=1 | 1.00 | 1.10 | 1.21 | 1.34 | 1.53 | 1.63 |
| **Added value** | 2017=1 | | | | | | |
| C20 | 2017=1 | 1.00 | 1.01 | 1.02 | 1.04 | 1.07 | 1.09 |
| C23 - Other | 2017=1 | 1.00 | 1.00 | 1.06 | 1.13 | 1.18 | 1.23 |
| C - other | 2017=1 | 1.00 | 1.03 | 1.08 | 1.17 | 1.26 | 1.34 |

### 2.4.3 Key assumptions, scenarios and border conditions

Key assumptions and border conditions for industrial sector can be summarised into clusters and are presented in Tab. 20. Technology specific assumptions per industrial branch are presented in the section 2.4.4 Model structure.

**Tab. 20: Key horizontal assumptions and measures included in the REES-IND model**

| **2018** | | | **2050** |
|---|---|---|---|
| **Measures already in place** | | **Developing technologies that will make a significant contribution to reducing emissions by 2050** | |
| **Energy efficiency & RES** | **Resource Efficiency** | **Synthesis gas and hydrogen** | **CCS and CCU technologies** |
| **Fossil fuels are** replaced by electricity technologies **(Heat Pumps, furnaces), where electricity is** obtained from RES (wind, PV, hydro) and CO2 neutral fuels (**biogas, biomass**);<br>**Waste heat utilisation;**<br>CHP - especially in industries where there is a high need for heat (paper, chemical and pharmaceutical industry);<br>**use of** trigeneration in sectors where there is significant cooling need (food and beverage industry);<br>**System services** – District heating, demand side management. | EEF & RES measures are upgraded with **material efficiency measures**, such as:<br>increase in the use **of waste materials**;<br>light-weighting – less material, easier manipulation;<br>**reuse of products** – refurbished products;<br>**increasing product** life;<br>**Recycling**. | **Synthesis** gas, as a substitute for natural gas in energy-intensive and bio-waste industries (possibility **of own biogas production**).<br>**Use hydrogen** as a substitute for natural gas. | CCS and CCU technologies are envisaged with the possibility of storage or reuse close enough to the production location (or location itself). |

### 2.4.4 Model structure

*Methodology*

The core of the calculations is a dedicated commercial tool MESAP, which is a modern tool for the design of energy systems. It implements a reference energy system that describes the technical, economic, and environmental characteristics of energy conversions from the Slovenian energy system to simulate its responses to external influential parameters and aggregates calculations of detailed models of subsystems. In REES-IND, the energy system is modelled up to the level of energy demand, allowing analysis of all energy policy measures, both on use and energy supply side. The reference energy system is a free structure, which means that the model is open to adapt to different analytical requirements, which allows modelling of new technologies and different intensities of the transition to a low-carbon society. REES-IND model calculates energy demand for four energy intensive branches and for the rest of the industry. Schematic representation of the model is presented in Figure 27.

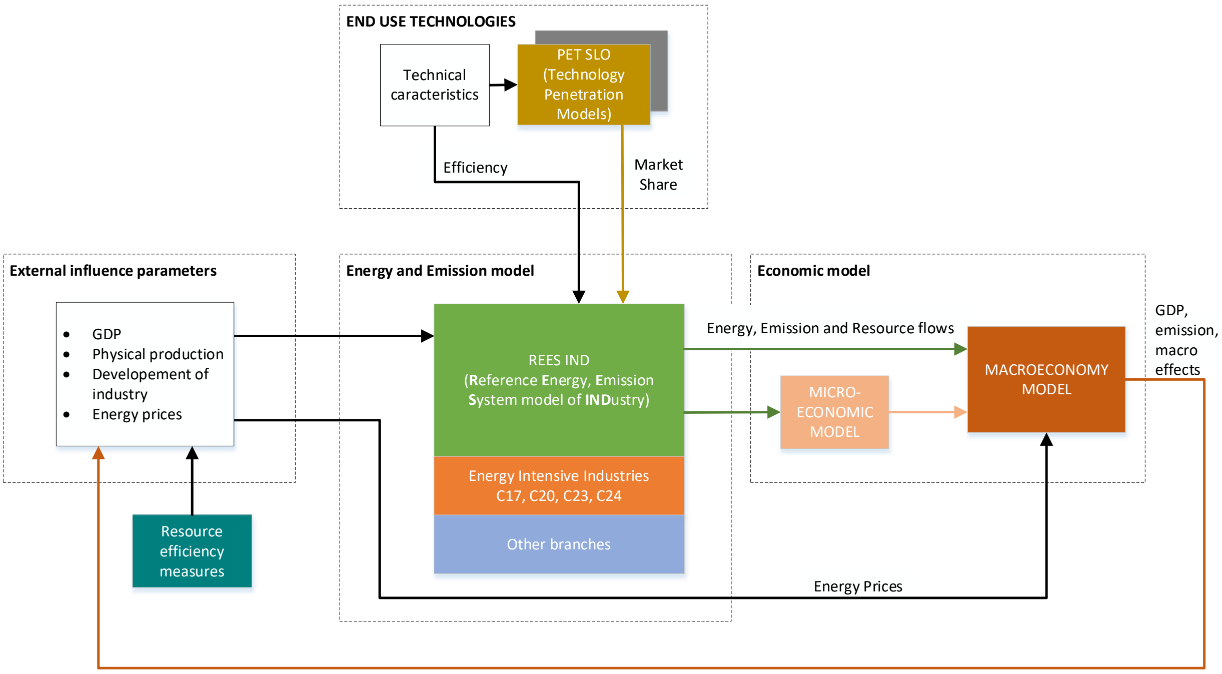

**Figure 27: Demonstration of the REES-IND model concept and model-to-model connections**

In parallel, standard and improved energy use technologies are modelled for technologies in use segments where efficiency gains are greatest. Based on technical, economic, and environmental characteristics, energy flows, costs and emissions are calculated in parallel for interchangeable technologies. This increases the transparency, consistency, and accuracy of estimates.

The model calculates:

- energy use balances (useful, final, secondary, and primary energy for the whole energy system and by sub-sectors, energy sources, technologies);

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- emissions of harmful substances ($SO_2$, $NO_x$, $CH_4$, $N_2O$, dust particles) from energy conversions (by sectors, energy sources, technologies, conversion levels and total emissions);
- costs related to the operation of the energy system and energy use (disaggregated by sectors or levels of conversion; costs are also divided into investment costs, costs for UUE promotion programmes, energy or fuel costs, maintenance and other operating costs, and others that can be displayed arbitrarily disaggregated by sectors; the model also distinguishes between taxes and other costs).

The technologically oriented REES-IND model thus provides a framework for a consistent and uniform approach to the identification of instruments, measures, and end-effects in different industries.

### *Technologies, sectors, processes*

The processes of horizontal technologies are included in model by individual industries, which allows analysis of the effects of energy efficiency strategies. The following processes or technologies are considered: electrolysis – aluminium, electric arc steel furnaces, thermal processes and non-energy uses, compressed air, electric motors (frequency regulation), space heating and boilers, and cogeneration of heat and electricity. The schematic representation of the technologically oriented model is shown Figure 28.

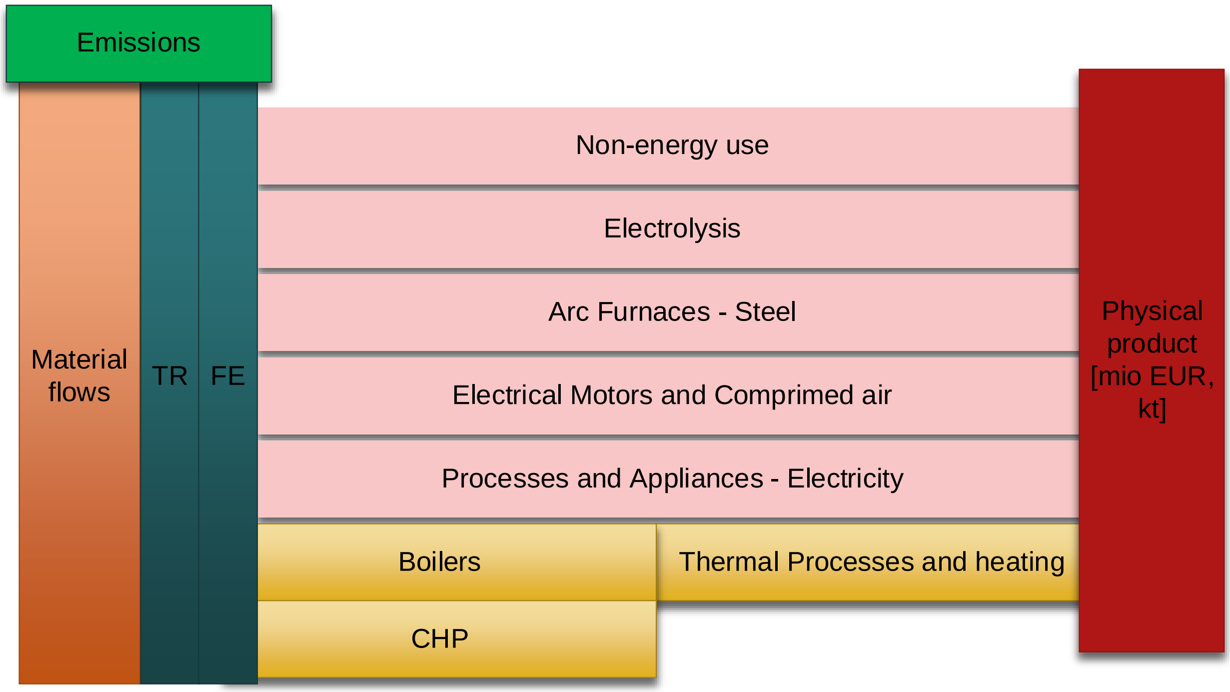

**Figure 28: Demonstration of the REES-IND concept and modelling of individual technologies in industry**

### *Energy Efficiency measures and RES utilisation*

Among the possible measures to reduce energy use and GHG emissions in industry, identified on the basis of measures envisaged and assessed in national strategies, action plans, operational programs, international literature (BREFs, IEA, Industrial Efficiency Technology Database) and data on energy use in industry, the following measures are modelled in the REES-IND model:

- electric arc furnaces for **steel production**: continuation of the implementation of measures to reduce intensity. These are: furnace updates, installation of "oxy fuel" burners, oxygen inhalation, use of natural gas for initial flame melting of the cartridge, preheating of the cartridge, inhalation of carbon foaming materials for slag foaming, etc.;
- thermal processes in **manufacture of basic metals**: reduction of specific heat use by waste heat recovery, expected technological updates during the period, replacement and modernisation of process machinery and equipment, and other organisational measures;
- thermal processes in **manufacture of paper and paper products**: reduction of the specific heat use by waste heat recovery, increase in production (reduction of specific use due to increased occupancy of installations), expected technological updates such as replacement and modernisation of paper machinery, and other organisational measures;
- thermal processes in the **manufacture of chemicals and chemical products**: reduction of the specific heat use by similar measures to the manufacture of paper and paper products; waste heat recovery, reduction of specific use due to increased occupancy of installations, replacement and modernisation of process machinery and appliances, and other organisational measures;
- thermal processes in the **manufacture of other non-metallic mineral products**: reduction of specific heat use by the following measures; waste heat recovery, reduction of specific use due to increased occupancy of installations, expected technological modernisation during the period, replacement and modernisation of process machinery and equipment, increased use of alternative fuels to produce clinker, and other organisational measures;
- energy-efficient electric motors, pumps, fans and frequency regulation; after 2017, it was necessary to ensure that the new electric motor is by IE3 standard, or at least by IE2 with frequency regulation;
- measures on compressed air preparation: leakage reduction, optimisation of water levels and optimisation of regulation to reduce compressed air consumption
- Energy-saving lighting - is considered in the context of other reduced energy intensity;
- Industrial boilers: implementation of higher efficiency measures and replacement of boilers, increased industrial CHP volume, replacement of existing old steam lineages with the partitioning of gas turbines, new plants with gas turbines, engines and new technologies (ORC, fuel cells, etc.);
- reduction of the energy intensity of all other processes due to the implementation of organisational measures, active energy management (Standard EN 16001, EN ISO 50001:2011 – Energy management systems, energy bookkeeping and targeted monitoring of energy use), increased occupancy and technological modernisation of production installations, etc.;
- waste heat recovery: the exploitation of waste heat, both high temperature and low temperature, is envisaged;

- replacement of energy sources in steel and glassmaking: after 2030, the replacement of gas furnaces for heat treatment in steel and glassmaking industry with electrical induction furnaces is envisaged;
- use of synthetic gas: assuming the central distribution of synthetic gas produced by RES.

### *Material performance measures*

Since modelling of material efficiency measures is a very demanding process, we have tried to rely on national strategic documents in the field. The Government of the Republic of Slovenia has prepared a so-called Roadmap towards the circular economy in Slovenia, which contains some guidelines for this transition. The key players in the circular economy should be industrial companies that process raw materials into products and semi-finished products, and companies that operate within their supply chains.

Roadmap states following potentials for the industrial sector: transition from products to services, from consumers to users, from ownership to sharing all of which can be promoted and implemented in the field of manufacturing. When we talk about the need to change the way we produce and consume, it is the area of manufacturing where the effects can be most visible. In Slovenia, we have large and internationally established companies, which are known for their transition from linear to circular models of business, along with several small business entities, who have become pioneers of circular solutions because of their innovation. Many of these are not known to the general public, so communicating good practices is crucial for promoting a circular transition and learning from those who have already entered the transition path.

Highlighted opportunities from the Roadmap:

- eco design - the design of products with the aim of easily maintaining, repairing, supplementing, changing their purpose and keeping them as long as possible in the cycle of use, and at the end of use as easy and efficient to disassemble and recycle;
- industrial symbiosis – we have good examples of market players who, by cooperating with each other, optimise material flows (which is waste for someone, is for another input or source);
- use of secondary sources - contribution to maintaining the value of materials that entered the production cycle and, in this way, extended their lifespan;
- transition to RES - an integral part of the commitment to the transition to a low-carbon society and a well-established concept in Slovenia;
- innovative materials - contribute to less burdening the environment, they improve the characteristics of products and make them easier to maintain;
- limiting the use of rare materials – metals and minerals – is a major challenge for Slovenia and Europe, which depend on them - how to replace them, how to keep them in the local environment even after the product has been used (e.g., electronic equipment and appliances);
- transparency in supply chains ("fair sourcing") – good practices in Slovenia are also an example at international level and promote traceability of the origin of the material, thus the possibility of selecting business partners that follow the principles of fair trade;

- reducing the use of plastics (and its replacing) and reducing the use of hazardous chemicals - compliance with EU directives and implementation of concrete solutions in Slovenia, an incentive for activities not only on the part of manufacturers, but also raising awareness of users and changing their shopping habits.

To properly monitor and evaluate the measures of transition to a circular economy, it is necessary to establish appropriate indicators. Roadmap states that we are currently monitoring the following: material productivity - number of repair shops/reusable centres, number of green jobs, share of recycled raw materials at the entrance to industry, share of recycled materials in inputs, share of changed business models (from products to services or functions), green public commissions and use of renewable energy sources. For the purposes of modelling measures, we relied on available literature and summarised the measures that are relevant for the individual industry. In-depth interviews were also carried out with representatives of energy-intensive companies, with whom we also spoke on material efficiency measures.
It is envisaged that, despite ambitious strategies to reduce GHG emissions, emissions from steel, cement, aluminium, and plastic production will increase, which means exceeding the commitment of staying below 1,5 °C. In this context, the realistic prospects of achieving the objectives without additional measures are minimal. For these reasons, we continue to focus on technologies where, due to their nature (intensity, volume, high temperature processes), it is more difficult to apply the principles of reducing GHG emissions. Industry-specific measures are summarised by (IPCC, 2014, Edenhofer, et al, 2014).

### C17 Manufacture of paper and paper products

In its review of GHG emission reduction potentials by industry, the IPCC sets out the following options for individual industries (IPCC, 2014, Edenhofer, et al, 2014):

- the main sources of GHG emissions are the use of fuels and energy for paper and paperboard production; more than half of the energy generated in paper production is used for heat (paper drying in paper machines); according to some estimates (Laurijssen, De Gram, Worrell, & Faaij, 2010), the thermal energy could be reduced to 32 % by using additives, increasing the dew point and heat recovery;
- paper recycling is an important material efficiency factor, especially in the light of increasing biomass needs as a fuel; it is possible to adapt and apply innovative approaches in the formulation of input requirements of recyclable paper, although the market is volatile and recycling rates are already very high;
- the use of cogeneration technologies and electricity.

### C20 Manufacture of chemicals and chemical products

Very little information is available. There are considerable problems with data collection for this industry, as it is a very diverse sector. This is largely about increasing energy efficiency and using renewable energy sources. Substances used in production (e.g. extraction and cleaning solvents, etc.) can be effectively reused by regeneration or distillation processes.

### C23 Manufacture of other non-metallic mineral products

GHG emissions are derived from the combustion of raw material heating fuels and from the calcination reaction. The following options for reducing GHG emissions are envisaged:

- improving energy efficiency and fuel substitution, although around 50% of the GHG emissions resulting from the calcination process are unavoidable;
- reducing the use of cement products by alternative building materials, construction technologies, and improving material efficiency in processes;
- milling and transport account for around 10% of energy use, which may be from non-fossil sources;
- target approximation of BAT to reference values (2,9 GJ/t of cement for end-use energy or primary energy use 3,4 GJ/t of Portland cement);
- increasing the use of alternative energy sources, especially of biogenic origin;
- although the use of alternative energy sources relatively increases the specific use of energy (mainly due to pre-treatment and drying of energy sources), GHG emissions are decreasing;
- the development of new cement production and use technologies;
- material efficiency: cement is used in the manufacture of concrete or concrete products, whereby material efficiency can be achieved in the following ways:
    - by optimising or adding less cement to the concrete mixture;
    - recycling of concrete parts after the first life of the concrete product (which is different from recycling concrete waste into aggregates, and using the prescribed amount of cement);
    - with the technology of construction and use of concrete only where it is absolutely necessary;
    - using stronger cement or concrete requires a lower mass of built-in concrete (even up to 40% lower $CO_2$ emissions using ultra-strong concrete;
    - reducing the proportion of clinker in cement using fillers (gypsum, slag, flying ash, red sludge, calcite and other natural or processed substances (e.g. pozzolan));
    - prolonging the useful life of buildings and infrastructure (e.g. through better maintenance) or more intensive use of them.

### *C24 Manufacture of basic metals*

Slovenia does not have primary iron production, but it does have steel mills. The steel recycling market has been developed and operational for decades, although it has some shortcomings, e.g. reduction in the value of materials due to the gradual mixing of impurities and unwanted metals into steel cast irons, which is currently resolved by end-of-tap mode in terms of the collection of secondary raw materials instead of during the process of separating and managing the flows of secondary raw materials and metal waste.

Due to high temperature processes and cooling regimes, improvements in heat and energy recovery from process gases, products, and waste streams or secondary raw materials (e.g. slag) are possible, which enables the planning of processes (e.g. with the principles of lean production), the logistics of production or individual processes where intermediate stocks are

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cooled, and heating before treatment in the next process. Cooperation of otherwise competing factories and corporations through best practice platforms or best available technologies (comparison or benchmarking) enable the identification of good practices and their introduction into production with below-average results in terms of energy and material performance.

Since we do not have iron production in Slovenia, emissions to air from steel production due to the predominant use of electricity or natural gas are relatively less problematic. However, in the processes of production and treatment of steel, there are also flows of waste or secondary raw materials, which are mainly useful in the construction industry.

The current ratio of labour costs to input materials (iron or recyclable steel) still favours (more expensive) work, which is not stimulating to increase the circulation of steel materials, since recycling involves relatively higher labour costs. Of course, the entire industry that uses steel products, with the development of their products can reduce the relative steel content in them, which applies to both the automotive and construction industries (e.g. construction for longer service life). Increasing the intensity of use of vehicles and buildings (sharing, renting, etc.) can also significantly reduce long-term GHG emissions due to lower primary production, but it is true that extending the useful life also partially increases emissions during the use of products, where it is therefore necessary to find a suitable optimum.

The following measures are envisaged for the production of metals:

- use of electricity from RES;
- recycling: aluminium collection and recycling industry is developed, due to the energy intensity of primary aluminium production. Use of energy to produce aluminium from recycled aluminium is at the level of 5% of energy use for the production of primary aluminium, without including the processing and transport of secondary aluminium; elements in alloys also pose a major problem, so they should be controlled in material flows; not only $CO_2$, the additional emissions of GHG in production is represented by reducing agents and protective gases (in the production of aluminium CF4 and C2F6, and in the production of magnesium by SF6);
- the use of aluminium stamping residues by sticking, not remelting;
- improving casting efficiency (less waste);
- reuse of aluminium window frames and facade cladding when demolishing buildings; modular construction for longer service life and greater possibility of reuse of prefabricated products.

These measures are very difficult to integrate into a planned model, which is why we are dealing with material efficiency by industry sectors, mainly through the feedback link of each measure and physical production, resulting in lower material, energy, and emission flows.

*Connections with other models*

Several sub-models are thus included in the set of models for the analysis of energy strategies. The overall analysis takes place in four stages:

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Firstly, the model for market penetration assessments of energy-efficient technologies (PET SLO) calculates the market shares of individual energy efficiency technologies by end-users in response to changed price signals, financial incentives, and information campaigns. Technologies that are gaining ground as result of regulations on minimum energy efficiency requirements (buildings, appliances, products) are modelled separately. Energy efficiency measures in energy-intensive activities are also modelled separately. Estimates of the market shares of individual technologies and their costs are input for the REES-IND model.

REES-IND calculates the prospective energy end-use balances specifically for energy-intensive industries (manufacture of paper and paper products (C17), manufacture of chemicals and chemical products (C20), manufacture of other non-metallic mineral products (C23) and manufacture of basic metals (C24)) and other industries and estimates local electricity production based on the shares of different technologies in the end-use structure and links with influential parameters. The model allows separate treatment of measures for the sector included in the European Emissions Trading Scheme (EU ETS).

The model calculates other balances for the entire planning period: primary and secondary energy, emission balances ($CO_2$, $CH_4$, $N_2O$, $SO_2$ and $NO_{X)}$, material flows and total costs.

The results of the model are led into a macroeconomic model, which then determines the effects of selected measures on macroeconomic aggregates such as GDP, employment, and feedback on energy use and emissions.

*Future development of the model and research challenges*

Energy intensive industries have been modelled separately enabling branch specific energy and emission flows calculation. The industrial model has been interlinked with the macroeconomy model which represents a first in Slovenian »modelling« environment.

The manufacturing industry is one of the main and most export-oriented sectors in the country. On the other hand, it heavily dependents on imports and it is one of the main consumers of materials, water, energy, and one of the largest producers of waste materials. Circular business models and associated value chains can be implemented perfectly in manufacturing – starting with eco design, the promotion of new materials, energy efficiency, the possibility of maintenance, repair, refurbishment, and ultimately recycling of products and incorporating these measures in the models is one of the biggest future challenges. Furthermore, the lack of national strategic basis for future industrial development represents a significant hurdle when developing such models. Also, the introduction of economic optimisation models in the process of technology selection is foreseen.

### 2.4.5 Model results

The projection of energy consumption and emissions in industry is a particular challenge as we are today on the threshold a new industrial era, the era of ‘new industrial paradigms’, Industry 4.0, based on information and communication technologies (ICT) and universal device connectivity (the ‘IOT - internet of things’). Decarbonisation of the industrial sector represents a particular challenge, given the high share of natural gas consumption in manufacturing, especially in energy-intensive activities (manufacture of paper, cement, steel, aluminium and chemicals). The

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integration and implementation of substantial efficiency measures that are crucial for the transition to a circular economy represent an extremely important and topical developmental trend in industry.

The most important result of the REES-IND model is the final energy consumption, since most of the emissions are directly linked to the energy consumption (excluding process related emissions). Figure 29 presents the projection of final energy consumption per addressed scenarios for 2020, 2030 and 2050 considering assumed scenario assumptions.

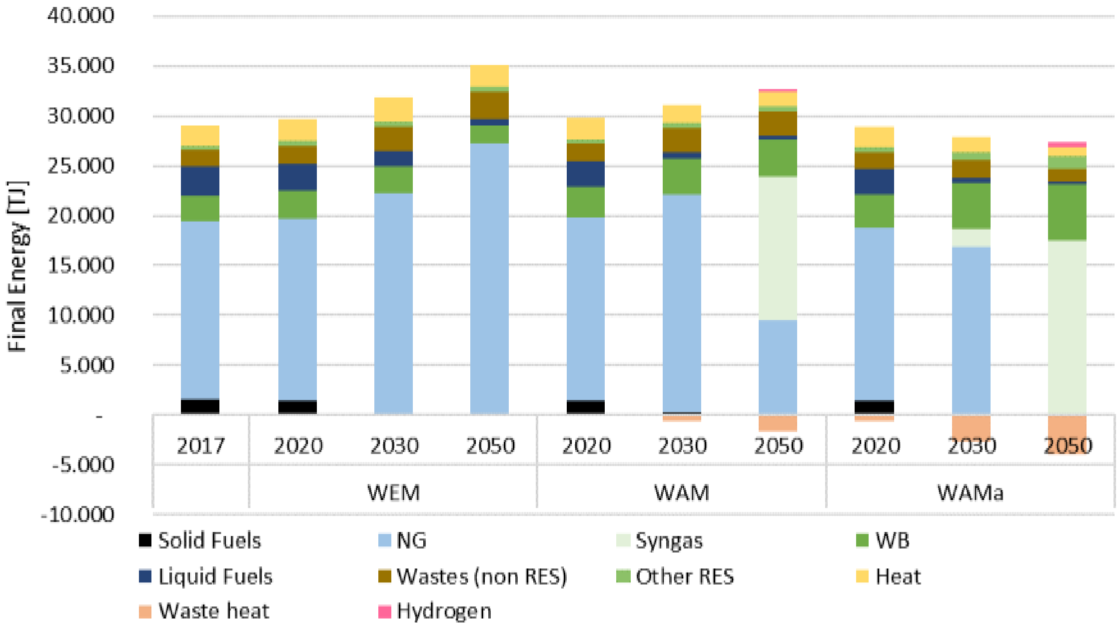

**Figure 29: Final Energy use in industrial sector per scenario (With Existing Measures WEM, With Additional Measures WAM and With ambitious Additional Measures WAMa)**

Results of industrial model were used to prepare important climate related strategies such as National Energy and Climate Plan (NECP) and Long-term Climate strategy.

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## 2.5 District heating expansion and CHP cross sectorial

### 2.5.1 Purpose of the model

District heating and cooling (DHC) model is a part of REES-SLO model and is being used to calculate energy demand and overall final energy use in the sector based on the energy demand of the building stock, efficiency of the system and energy carriers. District heating and cooling (DHC) could play an essential role in the cost-effective decarbonization of the EU energy system and compared with alternative scenarios.

The DHC model was developed in order to enable better expert basis and knowledge in order to support strategic decisions-making towards decarbonisation of the building stock and overall energy supply. Its main objective is to develop scenarios for the long-term development of energy demand, greenhouse gas emissions and air pollutant emissions. It considers a broad range of mitigation options combined with a high level of technological detail. It consists of two sub-models:

1. DHC model of existing systems
2. DHC model of new systems

The model of existing DHC system can address various research questions related to energy demand, GHG and air pollutant emissions on the national scale in the energy supply from DHC. It covers almost 100 existing systems in Slovenia. It tackles the questions regarding future restructure of DHC systems from the aspect of system efficiencies and energy sources.

DHC model of new DHC systems offers to determinate the potential of DHC areas, that can be used for either construction of new DHC systems or extension of them by using GIS methods, but these mainly present a technical potential. If buildings are located close to one another, it is often cheaper to construct a DHC pipe and share a DHC production unit than it is to install a separate heating system in each building. Hence, analysis of economic and social aspect was added. Such model enables to identify new DHC areas that are economically viable and distinguishes centralized and decentralized heating systems.

Models include scenarios for the future demand of individual energy carriers like electricity, fuel oil, biomass and also scenarios of penetration of synthetic fuels, calculations of energy saving potentials and their impact on GHG and air pollutant emissions, ex ante policy impact assessment low carbon transition scenarios.

During LIFE Climate Path 2050 project the following improvements of the model have been made:

- The entire model was updated and calibrated up to 2017 from the aspect of energy consumption the DHC supply sector as a reference point.
- The modelling of the existing DHC status is based on bottom up approach.
- The scenarios of future fuel-based boilers phase out projections, that are dictated by national regulation, have been integrated through share of used technologies.
- Modelling period has been prolonged. Previous model made calculations until 2030. In the updated model calculations are made until 2050.

- DHC model of new DHC systems is completely new and enables to assess technical and economic potential for (1) expansion of existing DHC networks and (2) new DHC areas.

### 2.5.2 Model Inputs

*External influencing factors*

For DHC systems, the key external factor is the development of the international fuel price, population density and heating demand. Future final energy consumption will also be affected by global warming and the energy renovation of the building stock, since the improvement of energy efficiency will result in decrease of the heat demand. The joint use of thermal energy from DHC systems will be highly dependent on the policy of network expansion, so we consider it as an internal measure of sectoral policy.

### 2.5.3 Key assumptions, scenarios and border conditions

Figures below present the main assumptions used in the District heating expansion and CHP model. Figure 30, Figure 31 and Figure 32 shows the market shares of District Heat generation for different scenarios. Main assumptions are hence:

- increase of RES energy sources;
- increase of waste heat utilisation;
- CHP development scenarios: switch from coal to NG and RES;
- reduction of network heat losses.

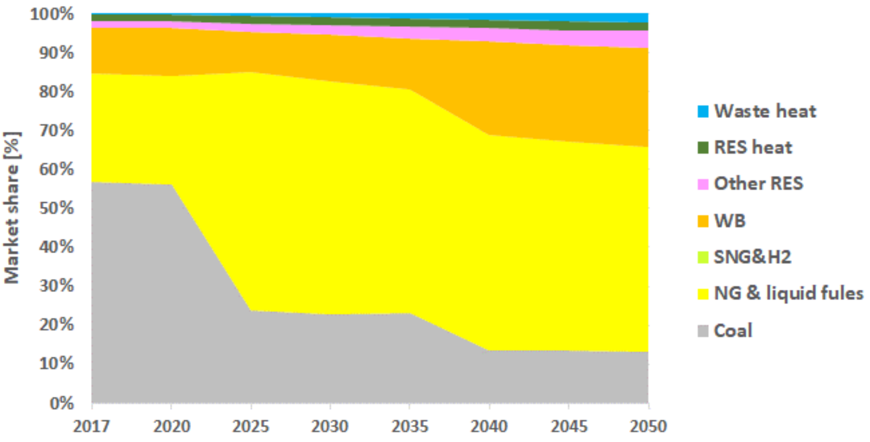

**Figure 30: District heat generation market shares, scenario: With Existing Measures – WEM(WEM(OU))**

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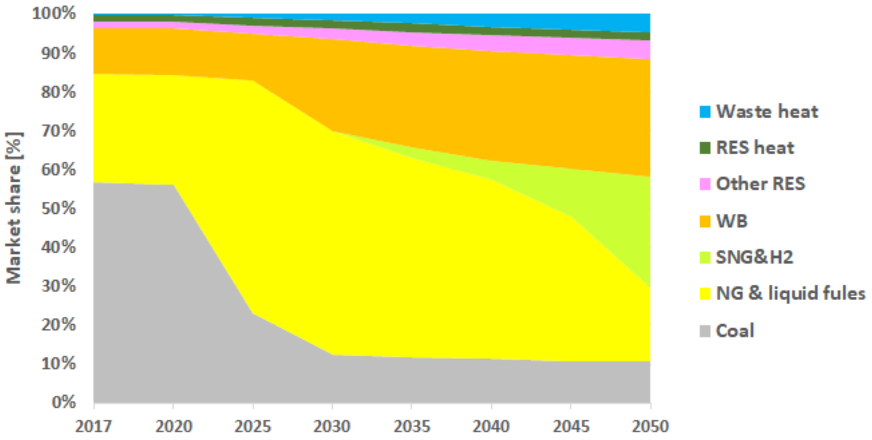

**Figure 31: District heat generation market shares, scenario: With Additional Measures –WAM(DU)**

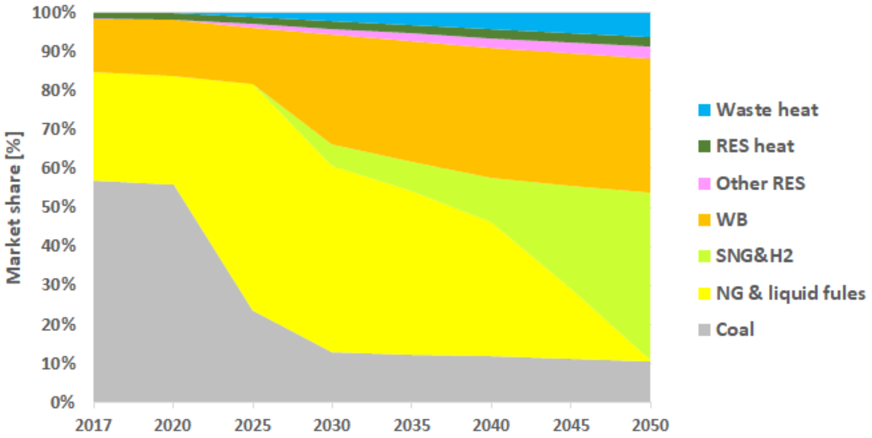

**Figure 32: District heat generation market shares scenario: With Ambitious Additional Measures – WAMa(DUA)**

The CHP capacity per scenario used as an assumption in the District heating expansion and CHP model are presented below (Figure 33, Figure 34, Figure 35). Also, the reduction of district heating heat losses has been assumed as presented in Figure 36. WEM(OU) represents the scenario With Existing Measures (WEM), DU With Additional Measures (WAM) and DUA represents scenario With Ambitious Additional Measures (WAMa).

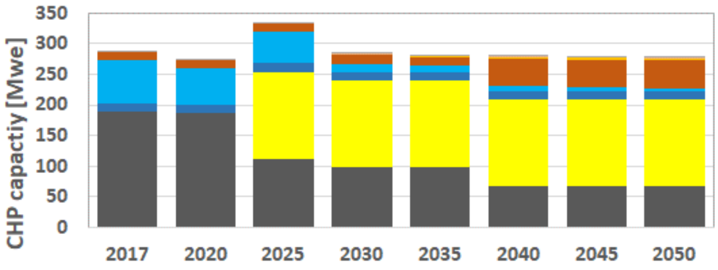

**Figure 33: CHP development scenario: WEM(WEM(OU))**

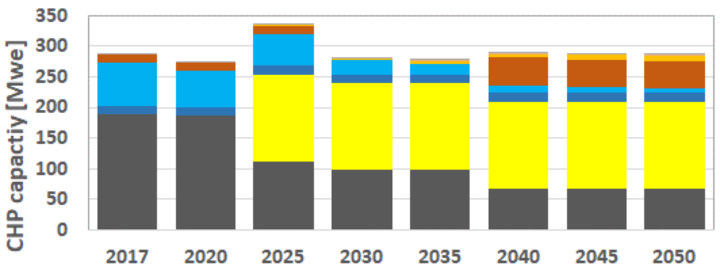

Figure 34: CHP development scenario: WAM(DU)

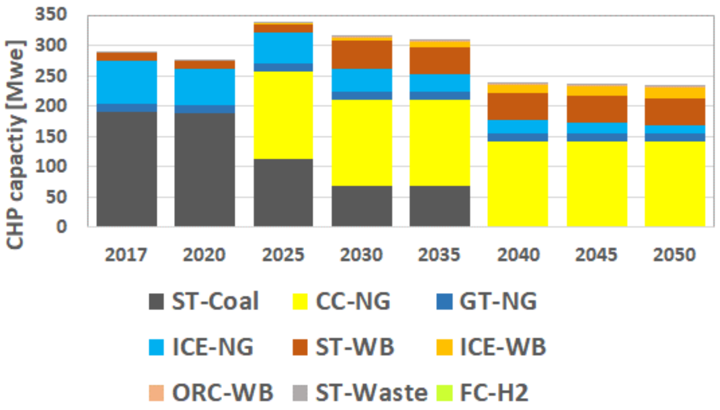

Figure 35: CHP development scenario: WAMa(DUA)

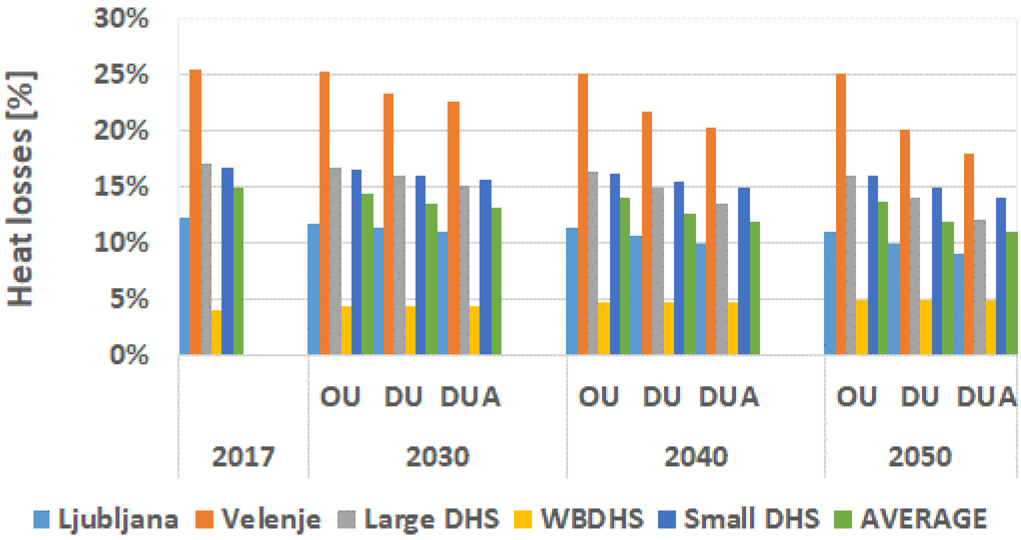

Figure 36: Reduction of district heating network losses by systems by scenarios

### 2.5.4 Model structure

*Methodology*

The section presents the developed framework, which includes methods to calculating energy demand on the basis of actual condition of buildings on-site, methods for establishing heat-pump potential on location for three types of heat pumps and the identification of existing DH (District Heating) networks. Furthermore, it establishes methods for assessment of economic viability of new DH networks, which includes the newly developed cost-effective area model, which determines the area of new DH network that is economically viable. All models have a 100x100 m resolution.

#### *Heating demand*

The information of aggregated heat demand is described through heat map, which reflects the demand for energy need for heating and domestic hot water, based on actual condition of the buildings. The typology consists of a classification scheme grouping buildings according to their size, age and further parameters (age of technical systems, year of partial/full renovation) and a set of exemplary buildings representing these building types.

Residential buildings are classified according to two buildings types, single- (SFH) and multi-family house (MFH), six building age classes, and four classes of buildings renovation status. Similarly, 14 building types were identified in the service sector, based on the use of buildings, three building age classes and four renovation status classes, altogether 154 energy classes. Energy for hot water preparation is based on type of building.

#### *Heat pump potential*

The following sections presents the methods for the assessment of air-source heat pumps (ASHP) potential and ground-source heat pump (GSHP), based on ground-water heat pumps (GWHP) in alluvial aquifers and ground-coupled heat pump (GCHP) systems, i.e. borehole heat exchangers (BHE) in geological layers.

#### *The most competitive technology - ASHP*

As a decentralized heating systems unit, biomass boilers and air-source heat pumps (ASHP) are considered as the most competitive technologies in rural areas, while in urban this is ASHP only due to air quality protection. Technical potential of ASHP as de/centralized system is not limited.

#### *Shallow geothermal energy*

Shallow geothermal energy potential (SGEP) was assessed for two types of GSHP installations: water to water systems (W-W), i.e. groundwater wells heat exchangers and brine to water (B-W) vertical BHE. The potential of thermal exploitation of groundwater depends on the presence of shallow groundwater in sufficient quantity and without competing with the use of this resource for drinking water. Aquifers parameters such as hydraulic gradient, hydraulic conductivities, aquifer thickness and effective porosity were considered for the determination of usable

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geothermal energy. The main criteria for BHEs potential were: ground temperature, thermal conductivity, heat flux and heat capacity. SGEP was estimated for areas with buildings, i.e. areas with heat demand density.

### *Spatial constraints*

Only areas of narrowest (VVO I) and narrower (VVO II) water protection areas and protected artesian aquifer were excluded for GSHP installations, in spite of the fact that they are also allowed on some of water protection areas, either as exemptions or allowed under specific conditions.

### *Entry data for geothermal parameters*

The main influencing parameters on BHEs potential are thermal conductivity and ground initial temperature. Other two parameters, less decisive for the design of installation are volumetric heat capacity and heat flux density. For the purpose of geothermal parameters (GEP) estimation, four maps (GIS data layers of those parameters) were produced for Slovenian territory on a large scale (1:250.000).

### *Methods and criteria of shallow geothermal energy potential assessment*

Size of geothermal energy installations was calculated using the main environmental conditions and parameters of the subsoil encountered on the Slovenian territory, in order to estimate the spatial distribution of SGE (shallow geothermal energy) in MWh/h per cell 100 x 100 m, along with economic parameters for six different building types and usage profiles.

Exploitability of the shallow geothermal energy was considered as the minimum required distance between neighbouring GSHP systems. For open systems a criterion of less than 1 °C temperature difference between disturbed and undisturbed ambient was used as a minimum distance between neighbouring GWHP installations. The other criterion was the thermal plume of 3 °C temperature difference does not exceed 100 m distance from injection well (Figure 1 - left).

For closed systems we used the criterion of one half of the BHE depth as a minimum distance between different neighbouring BHE installations as having negligible thermal influence between them (Figure 1 - right). Neighbouring installations can consist of single BHEs or two or multiple BHEs (fields). The number of BHEs in one system depends on geothermal parameters mentioned above. As the minimum distance between BHEs within one system was set to 7 meters.

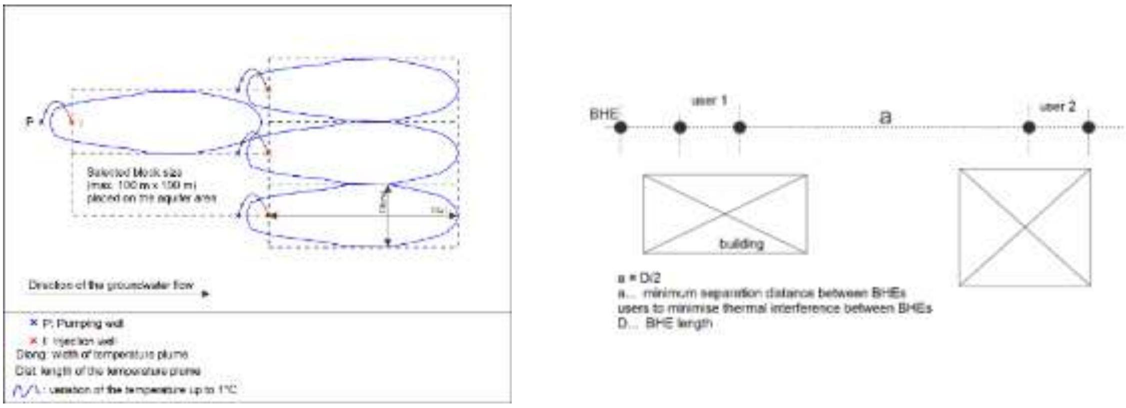

**Figure 37 Maximum possible groundwater temperature spreading indicates the thermal technical potential (left) and temperature influence on the ground for BHEs potential estimation (right).**

### Existing DHC infrastructure

The existing infrastructure in terms of existing DH networks was evaluated and taken into analysis using GIS. Natural gas DH were not taken into analysis. An extension of 250 m was assumed in order to consider future DH extensions. Polygons delimiting the zones within the supply zones of DH are used to distinguish areas with or without out buildings from the district heating polygons. In this manner, areas with potential for new DH systems and existing areas with energy supply from DH networks are separated.

### Economic assessment

The economic potential of new DH area depends on the presence of existing DH network and is expansion potential, possibility of exploitation of the technical potential on site and economic viability based on LCC (Life cycle costing) comparison with the competitive technology in dense/rural areas. The DH is economically viable if the energy price is competitive, i.e. if the LCC of DH solution is lower to the competitive decentralized system(s).

### Cost effective solution

Energy efficient measures is considered cost-effective when the cost of implementation is lower than the value of the benefits that result over the expected life of the measure. Both are based on comparing the costs and priced savings of a potential action. By ISO 15686-5, net present value (NPV, Equation 1) is a standard measure in life cycle cost (LCC) analyses. It accounts all costs of initial investment, operation and maintenance costs, replacement cost, and end-of-life costs including residual value. It is especially useful when project alternatives that fulfil the same performance requirements but differ with respect to initial costs and operating costs, have to be compared in order to select the one that maximizes net savings. The standard approach to deciding alternatives in terms of LCC is the selection of an alternative with the lowest net present value of costs.

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$$NPV = \sum_{n=1}^{p} \frac{C_n}{(1+r)^n} \qquad \textbf{(1)}$$

where; *NPV* is net present value; $C_n$ is cost occurred at year n; *n* is the year of cash flow; *p* is the life cycle and *r* is the discount rate.

### *Cost effective area model for district heating*

The following subsections describe the *cost-effective area model for DH* to examine potential for new DH areas. The costs are divided into production costs and distribution costs. Aggregated costs define the total cost of supplying an area with DH. Costs are given as long-run marginal expenses – investment, operation and fuel costs, which enables a comparison between technologies. In dense areas, the most competitive technology is air-source heat pump (ASHP) only, while in rural a biomass boiler is considered as an option as well. Investment and other cost related to technologies used represent the current market condition in the past 6 years.

### *DH costs*

For the calculation of annuity, 6% discount rate was used and 30 years investment lifetime and 1.8 MEUR/MW of specific investment in geothermal DH, 0.65 in ASHP system, using 3,000 full-load hours. The plot ratio of each hectare grid cell was used to determine the corresponding effective width value. By using the methodologies and models explained in the previous sections, the potential for new DH areas is examined. This is done by finding the cost of supplying DH to areas that do not currently have it and comparing it to other competitive technology with LCC.

### *Iterative approach to spatial analysis for new DH areas*

The proposed approach checks, from the perspective of each grid cell, the possibility of a new DH areas, taking the observed cell as the centre of a new possible DH. The approach gradually analyses all neighbouring cells and checks for economic feasibility. If the condition is met, the DH grid further grows and repeats the steps, until the analysed size is not economically feasible anymore, i.e. when NPV of competitive technology is lower than with DH system.

For the identification of new DH areas, a cost-effective area model was developed that consists of next steps (Figure 38):

1. ***Choose next cell***: The algorithm checks the possibility of a new DH for each grid cell. When finished, the algorithm checks next, neighbouring cell.
2. ***Minimum heat density***: The condition of minimum heat density is checked.
3. ***Maximum heat density in the area***: For i-th iteration the algorithm checks if the aggregated heating demand in the area is the largest.
4. ***Energy cost competitiveness***: The algorithm calculates DH cost and checks the competitiveness by using LCC and comparing the NPV with competitive technologies. If suitable, the algorithm expands the possible grid area for 1 row of external grid cells from the preceding step, returns to step 2 and checks the heat density of each, then

repeats the step 3 and checks for the grid centre point if the aggregated heating demand of grid cell is still the largest within the observed area and then calculates economic analysis again. If the DH price is not competitive, the algorithm progresses to step 5.

5. ***Identification of potential on-site and append area***: For the identified areas, where new DH networks is possible, the algorithm check the maximum availability of GEP (geothermal parameters), appends the area to final results and progresses to next cell.

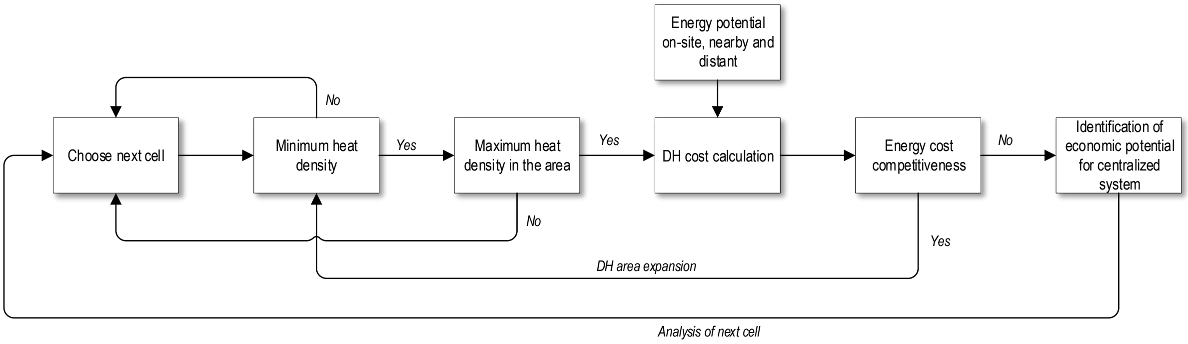

**Figure 38. Cost effective area model for identification of new DH areas.**

The calculation of costs differentiates the following five heat densities considering sparsely populated rural and densely populated areas: 1. CAT: 0 – 100 MWh/ha, 2. CAT: 100 – 200 MWh/ha, 3. CAT: 200 – 350 MWh/ha, 4. CAT: 350 – 600 MWh/ha and 5. CAT: > 600 MWh/ha. For the presented case study, minimum energy density of 100 MWh/ha was chosen.

### *Technologies, sectors, processes*

The DHC sector will play a bigger role in the future than it has today due to the fact, that cross-sector connectivity will be needed in order to optimize the costs of reducing emissions. The sector will also play an important role in energy storage and as such also as a connecting element between the heating and electricity production sectors and through electricity also with other sectors, e.g. transport in order to manage the growing dynamics of electricity production and consumption. Therefore, the additional measures envisage the expansion of district heating and cooling networks, connection to the electricity system and a significant reduction in GHG emissions from heat production, while in the ambitious scenario - full decarbonisation.

**Tab. 21: Scenario design for DHC systems.**

| Addressed field | Scenario measures | | |
|---|---|---|---|
| | **WEM – scenario With Existing Measures** | **WAM – scenario With Additional Measures** | **WAMa – ambitious scenario with additional measures** |
| **Expansion of the district heating and cooling network** | Current dynamics of development | Expansion according to the criterion of consumption density (economic criterion) - necessary to reduce the need | Expansion wherever the criterion of heat and cold consumption (compliance with additional benefits) is |

| Addressed field | Scenario measures | | |
|---|---|---|---|
| | WEM – scenario With Existing Measures | WAM – scenario With Additional Measures | WAMa – ambitious scenario with additional measures |
| | | for heat per m2 of bilding area | met, low-temperature networks |
| **RES and excess heat** | Fulfilment of EZ-1 obligations | Significant increase in share | 100% RES and excess heat |
| **Connecting to the power system: heat storage, "power to heat"** | Current dynamics of development | Increasing the flexibility of DHC systems - providing system services of electric power systems (heat accumulators) | Maximum power system support, including seasonal storage (reduction of mains pressure in winter) |
| **CHP on NG and SNG** | Fulfilment of EZ-1 obligations | NG (+ CCS for bigger buildings) | SNG |

The future use of district heating will be mainly the result of an active policy and is therefore not considered among external factors. The district heat supply follows the use of energy source. Although, according to the scenarios, heat consumption in DHC systems will decrease in all sectors by 2050, the number of buildings heated by DHC systems will increase significantly.

Further planning of expansion of DHC systems in projections depends on the modelled energy demand from buildings that are not yet connected to the system and their distance from existing distribution systems. Projections consider that (1) by 2050, as much as 80% of the heat in buildings will be supplied by DHC in areas where distribution systems are already installed today, and (2) that all buildings will be energy renovated. The last aspect affects the considered energy use in buildings and the reasonableness of expanding existing DHC systems. Expansion of existing DHC systems is planned up to 500 m distance from existing distribution systems, where the criterion of minimum heat demand density according to the scenarios must be met, namely WEM: 350 MWh / ha / year, WAM: 200 MWh / ha / year and WAMa: 100 MWh / ha / year. For expansion areas by 2050, it is considered that 40% of the heat in buildings will be supplied by the DHC.

New DHC systems have been identified in areas where they are not yet present today, nor do they interfere with areas of potential expansion of existing DH systems. The criterion of minimum density of heat consumption according to scenarios (the same limits as for system expansions) and economic justification for (1) construction of a new system and (2) replacement of existing heating systems in buildings with thermal substations were considered. The economic viability of new systems is achieved when the investment in replacing existing combustion plants with a heating station (considering the investment in the system and the price of heat) is more justified than the most recommended technology for heating in densely populated areas (air/water heat pump).

The WAMa scenario envisages a large-scale expansion of existing systems and the installation of new DHC systems. This is a major challenge given the fact that energy end-use in buildings will be gradually reduced by 2050 due to energy renovations and new constructions of energy-efficient buildings, and consumption density is one of the main reasons for the sensibility of installing and expanding DHC systems. It turns out that there is a lot of potential for connections in buildings in the service sector, so the implementation of measures will increase the area of buildings heated by DHC from 4,775,000 m2 to 10,858,000 m2 or 127%. In the residential sector, there is the greatest technical potential for connections to DHC systems in multi-apartment buildings, so it will be necessary to encourage condominium owners to these systems.

**Tab. 22: Area and share of buildings heated by DO systems in 2017 and scenario until 2050.**

| | Heated floor area by DHC systems [1.000 m$^2$] | | | | Share according the entire building stock | | | |
|---|---|---|---|---|---|---|---|---|
| | 2017 | 2030 | 2040 | 2050 | 2017 | 2030 | 2040 | 2050 |
| **All buildings** | 13.153 | 17.338 | 20.513 | 24.251 | 15 % | 18 % | 21 % | 24 % |
| **Households** | 8.378 | 10.200 | 11.593 | 13.393 | 13 % | 15 % | 17 % | 20 % |
| **Service buildings** | 4.775 | 7.138 | 8.920 | 10.858 | 20 % | 26 % | 29 % | 33 % |

### *Connections with other models*

The model results are used in the energy balance and emission calculation module in MESAP, where scenario analysis approach is used.

### *Future development of the model and research challenges*

Future development can be extended in several ways:

1. **Better cross-sectors connectivity**: direct connection with building energy model and with electricity market. This would be pivotal for decision-making in the DHC sector, so the models will have to be further upgraded in a manner they'll enable more in-depth analysis on micro level.
2. **Better modelling of effect** of measures on model parameters – **connection between measures/instrument and model parameters**: Implementation of different decision models in the REES DHC model.
3. **Further upgrade of non-residential building typology:** extreme architectural diversity, insufficient list of installed technologies for building operation in public and other service building require a unique and detailed building typology. Although a major breakthrough was made in the scope of LIFE ClimatePath2050 project, there's still much more research to be done in the future in order to analyse the stock as detailed as the residential building stock.
4. **Use of other environment** for the development of the model – e.g. Python to enable more flexible development allowing faster update of the model and faster preparation of different scenarios and better-quality management.

5. **Better integration between building energy renovation model and economic model** that will enable faster and parallel estimation of costs of different energy renovation measures. Combining the results with the past trend it will enable to make more realistic projections of overall possible renovation extent on the building stock.

### 2.5.5 Model results

Results are presented on a local (Figure 5) and national (Figure 6) level in order to differentiate between the applicability and impact of both.

On a local level, SGEP potential is presented for Maribor city, where the results of GIS analysis show geographically explicitly in which areas buildings can be supplied either by GCHP or GWHP. Using the map of SGEP, local authorities can assess the impact of proposed renewable energy developments and use the information to inform the local development planning process. It enables more informed decision making when planning energy use and infrastructure investment.

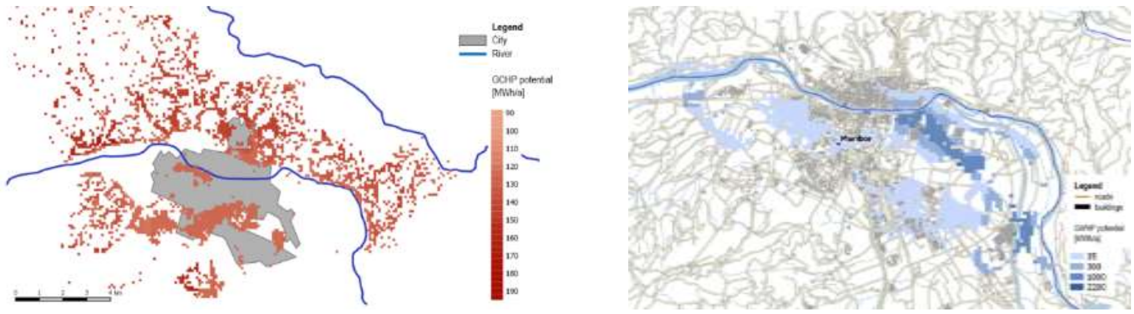

**Figure 39. SGEP for BHE systems (left) and for GWHP systems for cells in the aquifer area (right) for the Maribor**

On national level, the results are distinguished between the potential of the centre points of new cost-effective DH areas and the potential of the entire area of DH.

Centre points were observed in order to identify the potential of the main areas of high heat density where heat is supplied by decentralized units in mostly inefficient way and buildings in those area could easily be supplied by micro grid system. Overall the technical potential of such areas is 5.06 TWh. In economical way, large ASHP could supply energy in areas with aggregated amount of 4.9 TWh and 3.45 of HP with exploited shallow geothermal energy. In comparison, the energy consumption for heating using the HP technology in households in 2017 was 0.37 TWh.

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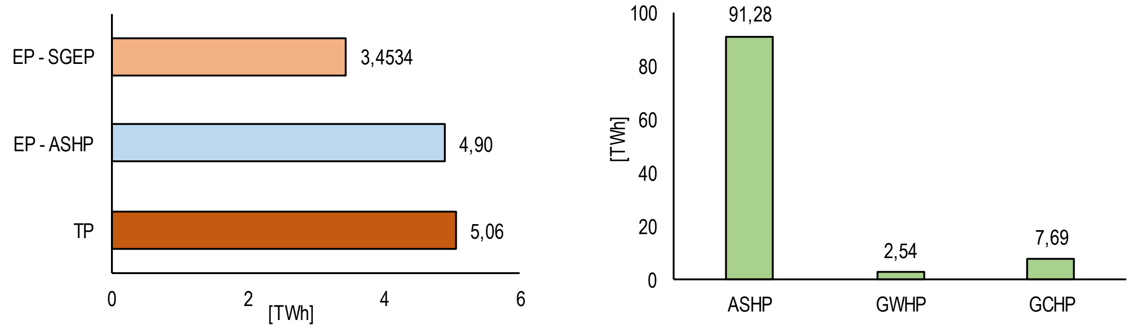

**Figure 40. Technological (TP) and economic (EP) potential of points of new areas (left) and economic potential of new heat pump-based DH areas (right)**

Observing the potential of entire areas, large ASHP in new DH networks present an enormous economically viable potential in amount of 91.28 of TWh. There is considerably less economic potential of new DH areas based on GWHP and GCHP in comparison to ASHP. The main reason is limited amount of extracted shallow geothermal energy on-site and temperature plume and interference between systems for GCHPs and the fact that the areas of high heat density and with the presence of aquifers already have an existing DH.

The results at the national level are presented in the following. The structure of heat production by energy sources is projected to change significantly in all scenarios in the following steps: by 2030 coal production in particular will decrease (switch to natural gas in the largest DH system), RES production will increase due to fossil sources, after 2040, the share of carbon-neutral gaseous fuels will increase. In the WAM scenario, the shares in heat production in 2050 are as follows: 36% from RES, 27% from SNG, 18% from natural gas, 14% from coal and 4% from electricity, only 0.5% from excess heat. In the WAMa scenario, production is less diversified: 55% is represented by heat from SNG, 39% from RES, 5% from electricity, excess heat reaches 0.7%, production from coal is terminated.

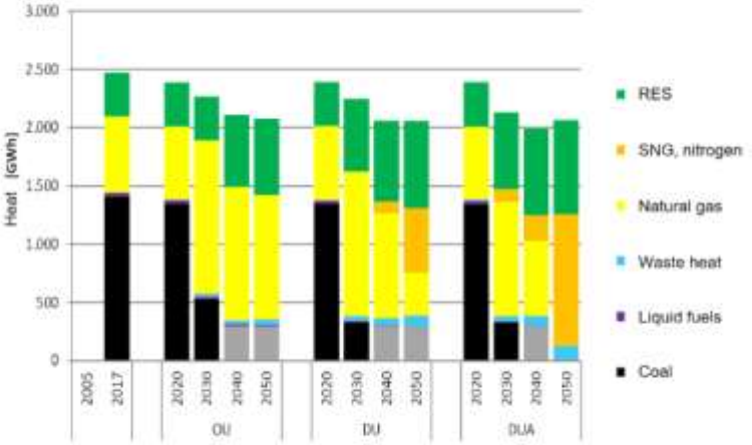

**Figure 41: Heat production by energy sources for WEM(WEM(OU)), WAM(DU) and WAMa(DUA) scenarios until 2050**

## 2.6 Distributed electricity production

Purpose models for distributed electricity production have not been developed in a general manner in the scope of LIFE ClimatePath 2050 project. On the other hand, several models for assessing the potential of distributed electricity production were developed. Results from those models were used as inputs for Power optimisation model described in the section *2.7 Optimisation of power sector operation (central system) for expansion planning*.

In that manner the model for assessing solar potential and battery instalment for self-sufficient buildings can be highlighted. The developed model is covering most important features of solar power production: the weather pattern, load curves and roof orientation and can be used either for single home-owners or small businesses. Typical applications and main benefits of the assessment are discussed and critically reviewed. The used model is suitable for use on single households or house clusters in scattered populated area and was developed based on extensive empirical knowledge.

More details about the model are available in the published scientific article by *Kovač et al.,* ***Assessing solar potential and battery instalment for self-sufficient buildings with simplified model****, Energy, Vol. 173, 2019, pp. 1182-1195*.

In addition, the model was tested against aggregate data from several rooftop solar power plants from Ljubljana, Slovenia with only power plants with all year-round data were considered. The weather data for year 2015 was used for the assessment. To account for loses due to shading of geographic features (e.g., near-by buildings and vegetation or terrain) is usually assessed on case-by-case basis. Since those tasks to determine real skyline are quite demanding, an averaged linear value, which is easy to incorporate was assumed. This approach might be to crude for single household analysis, however proved quite efficient in case of 250 different PVs.

### 2.6.1 Model results

In this section the distributed electricity productions potentials from Solar, Wind, small Hydro and biogas are presented in line with the potentials assessed and reported in NECP.

#### *Solar energy*

The generation of electricity in solar power plants (SPP) represents the greatest developmental and environmentally acceptable potential for increasing renewable electricity generation in Slovenia. In terms of sustainable use of space, it is rational to steer future development towards the priority of integrating solar energy into buildings, where technical electricity generation potential with regard to the available surface area is estimated at more than 20 TWh, the key limitation being the capacity to integrate solar power into the electricity grid, which, apart from the costs of power plants, is a crucial economic criterion for the development of solar power plants (From the network perspective, it is far easier to incorporate larger solar power units at locations with higher electricity consumption (all consumed on-site) or by connecting to the medium-voltage network).

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In the solar power plant development scenarios studied, different intensities of SPP development are analysed, which increase electricity generation from solar power plants to between 0.6 and 1.9 TWh (between 492 MW and 1 650 MW) by 2030 and to between 0.9 and 5.4 TWh (between 742 MW and 4 400 MW) by 2040. Up to 2030, this would require from 20 to 125 MW of SPP capacity to be installed annually, including approximately 80% are medium- and large-sized solar power plants (100 and 600 kW, a smaller proportion of free-standing SPPs of 1 000 kW on degraded or industrial sites), with the remainder being SPPs for self-supply in households.

The table below gives an overview of the generation of electricity in solar power plants (SPP) by year for the period 2017-2040 in line with the projections used in NECP.

**Tab. 23: Generation of electricity in solar power plants (SPP) in the period 2017-2040**

| | Unit | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| WEM | GWh | 284 | 306 | 427 | 556 | 724 | 904 |
| WAMa | GWh | 284 | 420 | 981 | 1866 | 3404 | 5361 |

### Wind energy

With regard to wind power plants, we have the problem of siting them spatially (areas classified as secured, protected and endangered areas) and in terms of social acceptability (due to dispersed settlement, there is a limited number of locations with appropriate wind conditions where in the vicinity there are no people or noise issues). Consequently, in the wind power development scenarios analysed, we remain within the potential of 415 MW, as estimated when the Renewable Energy Sources Action Plan, revised in 2015.

The table below gives an overview of the wind power generation in wind power plants (WPP) by year for the period 2017-2040 in line with the projections used in NECP.

**Tab. 24: Generation of electricity in wind power plants (WPP) in the period 2017-2040**

| | Unit | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| WEM | GWh | 6 | 6 | 10 | 15 | 23 | 32 |
| WAMa | GWh | 6 | 13 | 112 | 248 | 405 | 577 |

### Hydro energy

By means of small hydro-electric power plants (sHPP), traditionally, water flows are used to produce electricity throughout the country. Here too, for nature protection considerations (qualifying aquatic and riparian organisms and Natura 2000 habitat types, natural assets associated with water and protected watercourse areas) there are restrictions on the locations where hydro plants may be sited.

In the small hydro-electric power plant development scenarios analysed, existing capacity (155 MWe) is expanded to a lesser extent79 to 159 MWe by 2030 and to 177 MWe by 2040. This would represent an increase in current electricity production (383 GWh in 2017) to around 395 GWh in 2030 and up to 440 GWh in 2040, which is within the planned range indicated in the revised Renewable Energy Action Plan, revised in 2015.

The table below gives an overview of the power generation in small hydro-electric power plants (SPP) by year for the period 2017-2040 in line with the projections used in NECP.

**Tab. 25: Generation of electricity in small hydro-electric power plants (SPP) in the period 2017-2040**

| | Unit | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| WEM | GWh | 383 | 383 | 384 | 386 | 388 | 391 |
| WAMa | GWh | 383 | 385 | 388 | 394 | 412 | 439 |

### *Biogas*

Due to the relatively well-developed livestock breeding, livestock manure presents considerable potential for biogas production. A theoretical calculation shows that 315 GWh of electricity and 245 GWh of heat could be produced from the manure of cattle, pigs and poultry, and this raw material is also suitable for the production of biogas, which is a renewable gas and, in purified form, suitable for injection into gas networks and, as such, able to replace natural gas. Because farms are relatively small and geographically spread out, only about one-third of this potential is technically usable and, currently, rough estimates suggest that 0.2% of cattle manure potential, 13.8% of pig manure potential and 5.8% of poultry manure potential are used.

In the analysed scenarios for the development of electricity production from all types of biogas, the existing capacity (31 MWe) is increased to a smaller extent - up to 34 MWe by 2030 and up to 41 MWe by 2040. This would represent an increase from the current electricity production (127 GWh in 2017) to up to 170 GWh in 2030 and up to 245 GWh in 2040. These could be biogas production sites or biogas gas purification and injection and production in another location, it being especially necessary to utilise the available heat where and to the extent possible. The total biogas production potential is thus around 480 GWh in 2030 and up to 700 GWh in 2040. This includes biogas production from sewage treatment plants, waste treatment and landfill gas capture and agricultural gas production, with the main crops not being used, being aware that agricultural land is intended for food production.

The table below gives an overview of the power generation from biogas by year for the period 2017-2040 in line with the projections used in NECP.

**Tab. 26: Electricity production from biogas in the period 2017-2040**

| | Unit | 2017 | 2020 | 2025 | 2030 | 2035 | 2040 |
|---|---|---|---|---|---|---|---|
| WEM | GWh | 127 | 134 | 135 | 136 | 136 | 137 |
| WAMa | GWh | 127 | 135 | 151 | 169 | 204 | 244 |

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## 2.7 Optimisation of power sector operation (central system) for expansion planning

### 2.7.1 Purpose of the model

The first model of the Slovenian EES (Electrical Energy System = Power system), on which the Power sector optimisation model developed in the scope of Life ClimatePAth 2050 relies on, was developed in 2005 and complements it today in the light of specific requirements and processing. The development of the model was based on the experience gained from 15 years of work on this type of modelling.

Long-standing practice in Slovenia has shown the inadequacy of the use of foreign models in the determination of development plans for power plants, which are characterized by major specificities; inflexibility, high technical minima, provision of frequency services, high requirements for the provision of manual reserve, mainly only daily accumulations of Hydro power plants and their specificity, high energy power system openness and connectivity,.., and this should therefore be taken into account for the assessment of operation and planning.

Models, both commercial and other freely available, which can be used for larger systems, do not address these specifics, are the results for "small systems" like Slovenian are unrealistic. These were the main arguments for developing our own model.

In the past, our renewable energy sources model has focused on large HPP, but in the last period, mainly thanks to the LIFE project, attention has shifted to systemic integration and model integration mainly of solar and wind power plants. These are sources that were not previously directly and precisely included in the simulation, but only through annual cumulative values, which does not allow for a complex analysis of their characteristics and the impact on the EES. A proper evaluation of Solar PV and Wind is now also possible in our model.

### 2.7.2 Model Inputs

The preparation and analysis of data on electricity consumption are the basis for modelling daily consumption diagrams in the model for long-term planning of production development in the power system. It should be emphasized that the different sources of statistics do not provide the same basis but are only partially comparable. This is particularly true for statistics presented on an annual basis by the Energy Agency and hourly data published by ELES (Slovenia's electric power transmission system operator).

In our case, we relied on ELES's data, which have an hourly dynamic of consumption at the level of the transmission network. The starting point is the base year, after which the characteristics of the annual consumption are summarized. In our case, we started from 2016, which we later upgraded to 2017.

For the preparation of the model daily diagrams, we have started from hourly data on consumption, i.e. 8760 (365 x 24) hours or 8784 (366 x 24), and the case of a leap year. The hours resulting from the annual changes of time, spring and autumn are adjusted and considered accordingly.

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These data are then broken down by months of the year - 12 months. Each month presents the characteristic:

- working day;
- Saturday and
- Sunday,

and each is illustrated by 24-hour load demand columns. An example of daily load diagram with hourly load dynamics is presented in Figure 42. Where x axis represents the hours in a day and y axis represents the Power in [MW].

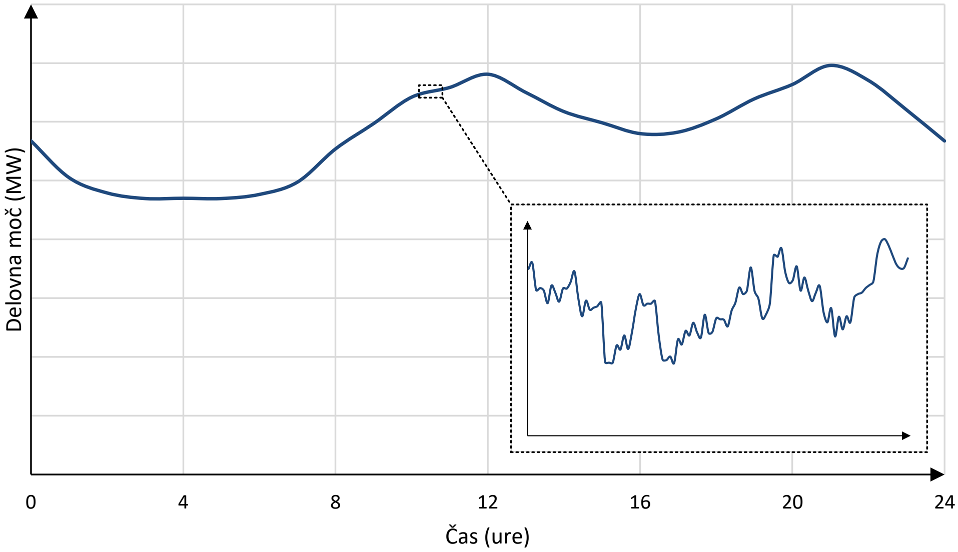

**Figure 42: Daily load diagram with hourly load dynamics**

Considering the historical facts, the most characteristic - representative days are those after the 15th day of each month. This old but still valid rule has been confirmed in more recent times. This finding/assumption is a starting point in the design of the daily consumption load also in our model. In this manner 8760 hours of annual workload are replaced by 12 (months) x 3 (characteristic days; weekday, Saturday and Sunday) x 24-hour load demand columns. It’s an 864-year-old data on hourly consumption loads and associated factors.

The hours do not represent the average, but concrete - actual loads that occurred in the system in the base year. For each hour in the "matrix," its share in the energy demand for a particular month is calculated, that the energy balance of the base year is maintained. This is also the key to generating daily load diagrams for the selected/projected time horizon.

The file dealing with consumption in the base year also contains data on electricity prices from the BSP SouthPool energy exchange, analysed in the same way as described hourly approach.

All input data is stored as excel files that are automatically read. The input file that defines the power consumption data represented by three Excel sheets, namely:

- first Excel Sheet named **Scenario** (Scenarij) represents the scenario is being analysed;
- second Excel sheet **named Data** (Podatki), represents the annual data on:
  - projections of electricity consumption at the level of the 'transmission system' – and interaction with the output data of the REES-SLO model;
  - and projections of electricity prices on the reference market;
- third Excel sheet, named **Consumption** (Odjem), represents the hourly data of the base year used in the analysis.

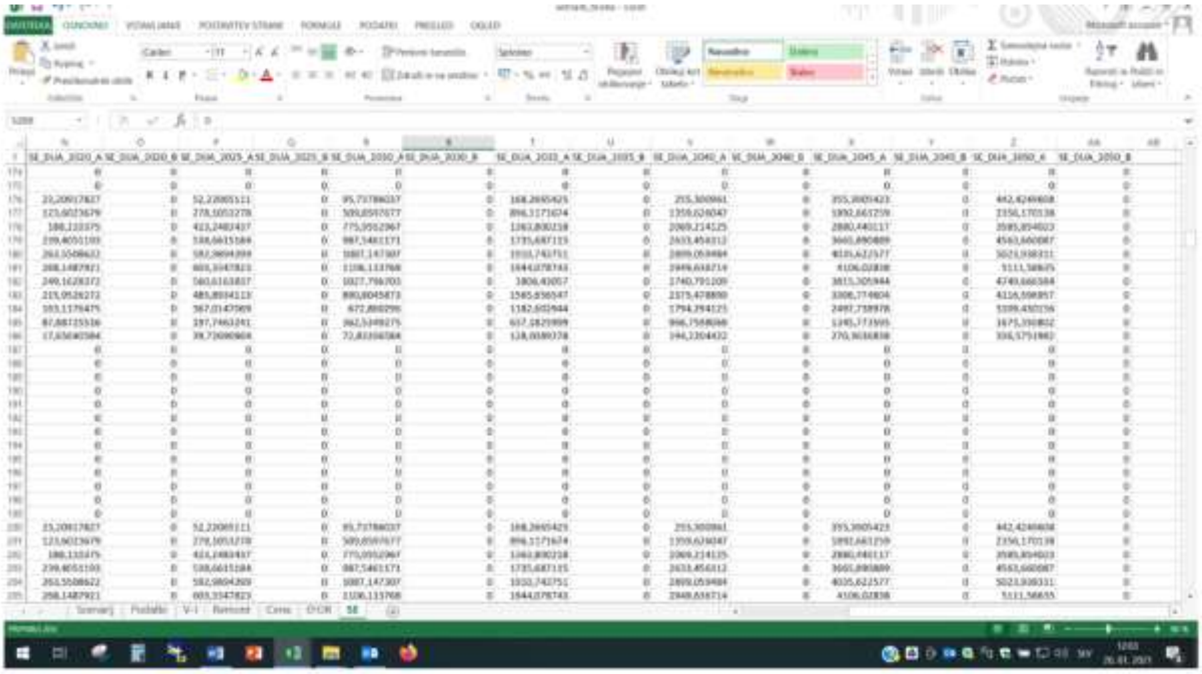

**Figure 43: An example of the input data preparation for the power generation scenario based assessment**

### *External and Internal Input Parameters*

The model external influence parameters are presented in the following. The model uses several input files that address the:

- data on electricity consumption projections at transmission system level:
  - base year data: hourly data may be used or weekly aggregate (according to the complexity of calculations vs. length of processing time), work week, Saturday and Sunday, according to the principle of 3 characteristic days x 24 hours or at the annual level 52 weeks x 3 characteristic days x 24 hours;
  - projections of electricity production for the specific year are calculated and addressed in line with energy security definitions and requested parameters;
- data on electricity prices:
  - base year data, 2016 (2017): Data on the prices is aggregated in the same way as data on electricity consumption, hourly data can also be used;
  - selection of reference power exchange – BSP Energy Exchange;
- technical data on producers — electricity providers:
  - **Solar power plants (SPP)**:
    - the characteristics of solar radiation in SLO are taken into account,

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    - in the model, all envisaged SPP are replaced by a single representational facility,
    - the specific probability design of electricity generation is considered;
- **Wind power plants (WPP)**:
    - the characteristics of wind potential of 1300 and 1800 hours per year are considered,
    - in the model, all envisaged WPP are replaced by two representational units, namely: VE_1300 and VE_1800,
    - the probability design of electricity generation from wind power plants is considered,
- **Hydro-electric power plants (HPP)**:
    - hydrological data cover available daily average hydrological data for Slovenian rivers;
    - the data is then transferred via linear factors to the locations of the objects;
    - technical-technological data: power, energy, pool size, denivelation and other limitations,
- **Conventional power plants and imports**:
    - Year of entry and exit from operation of the unit,
    - technical data of the units: $P_{max}$, Pmin, $q_{sp\_pov}$, $P_{PRO,\ PSRO,}$ length of overhaul;
    - environmental data: input-output concentrations, emission factors, fuel characteristics;
    - operating characteristics: band, trapezoidal, peak, reserve;
    - cost data: type of energy product, energy price, other cost variable and fixed components;
- **Import of electricity and connections**: simulation carried out considering NTC (Negative Temperature Coefficient Thermistor) and other restrictions, individual connections are simulated as virtual units with all necessary limitations and characteristics;
- **The export of electricity is carried out if/or**:
    - the available electricity and its price from the units in the country at the addressed hour is lower than the units provided by the import;
    - due to the inflexibility (high technical minimums) of units in operation and the lack of available storage;
- CHP: production is considered to be a forced production linked to the production of thermal energy (1), and a part that may be intended for the market (2).
- Data in between years:
    - overhaul cycles,
    - unplanned unavailability of units.

### 2.7.3 Key assumptions, scenarios and border conditions

Within the LIFE project, we carried out several calculations of the scenarios for the development of large power production installations by 2050. The project took place in parallel with the preparation of the National Energy Climate Plan, which was approved in February 2020 by the Government of the Republic of Slovenia and submitted to the EC.

Thus, common scenarios for both projects were developed. The aim of the programmes was to make the electricity and heat generation sector carbon neutral by 2050 under an ambitious scenario (With Ambitious Measures - WAMa).

The objective of achieving carbon-neutral electricity generation by 2050 requires major changes by 2030.

Scenarios were defined separately for:

1. large electricity generation facilities, diffuse electricity generation and electricity generation
2. district heating and cooling systems.

Projections of electricity consumption growth were obtained from the REES-SLO model for all three main scenarios WEM, WAM and WAMa, as well as projections of the development of dispersed production resources in the same way. Their dynamics and incorporation in the Slovenian power sector were considered at the hourly level.

Large installations for electricity generation play a key role in ensuring security of electricity supply, as they cover the difference from generation from dispersed sources and the necessary production to ensure security of supply.

**Scenario with Existing Measures - WEM**, which is of a comparative nature and provides for minimal additional investment in large installations. It foresees the completion of the chain of hydropower plants on the lower Sava River, the construction of the Mokrice hydropower plant, while other investments in large OVE are not foreseen. The growth of small dispersed resources is also less intensive.

**Scenario with Additional Measures – WAM,** envisages more intensive power sector development, it foresees higher production of electricity from large Hydro-electric power plants, as well as wind and solar, which are among the occasional renewable sources, in combination with electricity storage. This scenario partially harnesses the hydro potential on middle Sava river with the installation of 5 HPP units. The Kozjak Pumped storage hydro power plant is also envisaged.

**Scenario with Ambitious Additional Measures – WAMa** envisages even more intensive power sector development, foreseeing even greater electricity generation from large Hydro-electrical power plants. Thus, it is envisaged to build an entire chain of hydro power plants on middle Sava river, as well as two new pumped storage hydro power plants. Other small dispersed sources also have a higher intensity of market penetration.

### 2.7.4 Model structure

*Methodology*

The platform on which the EES Development Planning Model of Slovenia operates is Windows 10. Since 2015, we have been using Python as a software tool, an interpretive multifunctional programming language that supports dynamic data types, unlike the programming language C, in which the older versions of the model were written/programmed. Excel is used as an input/output (I/O) structure of the model.

### Basic characteristics of the model

The model analyses the narrow specificities common to the electricity generation sector. The model integrates the operation of both conventional producers and existing and planned renewable electricity sources into the total Power system.

The simulation-based model calculates the individual states of future development of electricity generation, subject to limitations.

Geographically it is limited to the production of technology covering large facilities in the area of R Slovenia and also includes links with neighbouring systems.

The model addresses the power production processes and for the selected time horizon, specifies:

- the schedule of starting and shutting down each production unit,
- the load on each production unit,
- calculation of LOLE (loss of load expectation) and ENS (energy not supplied) reliability indicators,
- formulate a market offering (power plants and imports) and a consumer curve (transfer-level spot) and a cross-section point;
- treat both existing and planned production units.

### Time step

The basic processing time step is one hour.

It is considered 864 hours in a given year. Calculations are transferred to the annual level on the basis of characteristic factors.

The time horizon (number of individual years) is arbitrarily identifiable, usually between five and 10 years of individual years, but they do not have to be defined sequentially. Input files must correspond to the selected time horizon.

### Probability design of the model

The model is probability-based. It addresses the following probabilistic characteristics of the slovenian Power system, namely:

1. **Probability assessment of hydropower** plants - hydrological flows on Slovenian rivers are addressed; Drava river, Sava river, Soča river and Mura river. The hydrological array under consideration comprises hydrological daily data (mean values) from 1971 to 2016.

   On the basis of that series, the production from individual HPP is calculated for:

   - Dry year – 5% probability of required hydrology,
   - Average year – 50% probability of required hydrology and
   - Wet year – 95% probability of the required hydrology.

2. **Probability assessment of the** production from **solar and wind** power plants - these are simulated as a single Solar or Wind replacement plant in the analysed year, considering the baseline hourly operating matrix, which is upgraded with an availability factor that is stochastically designed.

3. **Non-planned unavailability of thermal power plants, major CHP units and Imports**. Unavailability factors are applied based on the available literature and existing power production units' statistics from 1973 onwards for existing objects, and for new units and technologies.

A Monte Carlo simulation method is used for the calculation, carried out with a traceable baseline random function, allowing the resulting calculations to be repeatable and reproduceable.

Outputs from the simulation model can be recognised as "availability tables" - matrix that represent number of units by selected time intervals for addressed year.

Typically, convergence repetitions are selected up front to ensure the quality of the model output calculations. In our cases, the number of repetitions is between 100 and 1000, with the lowest number (100 repetitions) also ensuring good quality of results.

### *Technologies, sectors, processes*

The model addresses the following electricity generation technologies in large installations, $P_i \geq$ 10 MW:

- conventional coal-fired steam power plants with sub-critical and above critical parameters, conventional power plants and CHP,
- Fluidized Bed Combustion thermal power plants (CFBC, AFBC, PFBC),
- thermal power plants based on the gasification of fuels;
- nuclear power plants,
- conventional natural gas steam power plants,
- gas turbines; simple process,
- internal combustion engines,
- gas steam power plants,
- Hydro-electrical power plants of different powers and characteristics,
- geothermal power plants, as one combined facility at national power system level,
- solar power plants, as one combined facility at national power system level,
- different operating hours, as one combined facility at national power system level and one combined facility,
- electricity storage technologies:
  - Pumped storage hydro power plants,
  - Batteries and
  - Compressed Air Energy Storage (CAES).

### *Connections with other models*

The model is interconnected with REES-SLO model by using the REES-SLO model outputs, namely electricity demand, Solar, Wind, Biogas, small Hydro and CHP production potentials as input in the Power sector optimisation model. Furthermore, the model uses the same external influence parameters such as energy prices and prices for emission allowances.

The balances calculated with Power sector optimisation model are used also in the REES-SLO model when assessing the Primary energy balance and overall emission flows. It is evident that Power sector optimisation model plays a crucial role in the process of the scenario-based energy, economic and environmental assessment of the decarbonisation pathways.

### *Future development of the model and research challenges*

Future development of the model is strongly tied to the improvements in the statistical basis. Also, the load diagrams for dispersed electricity production and the inclusion in the hourly diagrams represent an important challenge. The connection direct connection with the models assessing the potentials for dispersed electricity production (solar, wind, CHP) is foreseen in the near future. For those potential assessment models, the connection with GIS (geographical information systems) is essential, hence a connectivity framework connecting various models has to be established in the future. Also, a lot of work has to be done in the field of modelling the different storage technologies.

### 2.7.5 Model results

As an example of the Power sector optimisation model results the assessment of the WAMa – nuclear scenario is presented in the Tab. 27.

The projections for the development of Slovenian power system are in line with the WAMa – nuclear scenario assumptions.

A significant contribution to new sources is made by solar and wind power plants. A significant increase is mainly due to the increase of solar production. The objective of successful integration of solar electricity will require various types of electricity accumulators from those included on the transmission network – pumped storage, to those (Power to X technologies, battery systems) placed on the consumer side.

The use of wind potential is significantly less intense than the solar one. Intensive use of hydropotential in large HEMs was also envisaged, but due to negative environmental assessments the programme was largely abolished.

In the context of the need for flexible and fast response production, the installed power of gas units is increased accordingly, but not significantly more than in other scenarios. Furthermore, CCS/CCU units for carbon capture and storage is predicted in TEŠ B6 unit in 2035. Power system reliability indicators, such as LOLE and ENS, are satisfactory with an appropriate set of large production facilities.

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**Tab. 27: Results of electricity generation development up to 2050, following scenario WAMa - nuclear**

| Scenario: WAMa - nuclear | unit | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| **Installed Power** | | | | | | | | |
| Peak load | MW | 2122 | 2169 | 2284 | 2439 | 2543 | 2602 | 2626 |
| Pi-Gas steam units | MW | | 140 | 140 | 140 | 140 | 140 | 140 |
| Pi-Thermal PP | MW | 980 | 890 | 580 | 494 | 494 | 494 | 45 |
| Pi-IMPORT | MW | 1025 | 925 | 1275 | 1275 | 1125 | 1025 | 1375 |
| Pi-Nuclear PP | MW | 348 | 348 | 348 | 348 | 1433 | 1085 | 1085 |
| Pi-Gas PP | MW | 474 | 448 | 406 | 651 | 651 | 651 | 651 |
| Pi-Internal comb. units | MW | | | 30 | 30 | 30 | 30 | 30 |
| Pi-Large Hydro | MW | 996 | 1024,1 | 1102,1 | 1198,5 | 1305,9 | 1336,9 | 1393,9 |
| Pi-Wind PP | MW | 10 | 70 | 150 | 240 | 335 | 390 | 415 |
| Pi-Pumped storage (turbine mode) | MW | 185 | 185 | 584 | 584 | 769 | 769 | 769 |
| Pi-Pumped storage (Pumping mode) | MW | 180 | 180 | 532 | 532 | 712 | 712 | 712 |
| Pi-Solar energy | MW | 400 | 900 | 1650 | 2900 | 4400 | 6125 | 7625 |
| | | | | | | | | |
| **Energy security Indicators** | | | | | | | | |
| LOLP | h | 2,944 | 6,736 | 7,734 | 2,149 | 8,567 | 3,897 | 5,517 |
| ENS | MWh | 365,8 | 706,6 | 972,3 | 272,0 | 1141,5 | 625,8 | 857,3 |
| | | | | | | | | |
| **Balance** | | | | | | | | |
| Demand | GWh | 13399,0 | 13700,0 | 14422,0 | 15403,0 | 16060,0 | 16433,0 | 16585,0 |
| Pumping | GWh | 511,1 | 511,1 | 1508,1 | 1508,1 | 2210,3 | 2199,1 | 2222,7 |
| Demand+Pumping | GWh | 13910,1 | 14211,1 | 15930,1 | 16911,1 | 18270,3 | 18632,1 | 18807,7 |
| Internal comb. units | GWh | | | 12,7 | 21,9 | 1,4 | 7,9 | 11,7 |
| IMPORT | GWh | 2521,8 | 2207,1 | 3137,6 | 2378,9 | 580,5 | 966,6 | 2038,2 |
| Gas steam units | GWh | | 700,6 | 687,3 | 711,6 | 704,2 | 702,9 | 703,6 |
| Thermal PP | GWh | 4105,5 | 3694,1 | 2877,4 | 2826,3 | 2391,9 | 2605,2 | 152,8 |
| Nuclear PP | GWh | 2680,6 | 2679,2 | 2680,1 | 2682,7 | 10733,0 | 8054,5 | 8059,2 |
| Solar Energy | GWh | 415,6 | 989,1 | 1441,1 | 3387,5 | 5338,7 | 7816,8 | 10102,7 |
| Wind PP | GWh | 13,7 | 113,6 | 247,2 | 403,3 | 574,0 | 683,5 | 730,9 |
| Gas PP | GWh | 56,4 | 52,9 | 84,9 | 174,9 | 121,9 | 84,0 | 128,3 |
| Pumped storage (turbine mode) | GWh | 387,9 | 387,9 | 1133,9 | 1133,9 | 1674,9 | 1664,9 | 1673,8 |
| Large Hydro | GWh | 3949,9 | 4067,3 | 4334,0 | 4653,6 | 4927,4 | 5015,7 | 5174,0 |
| EXPORT | GWh | 221,7 | 681,4 | 707,0 | 3294,1 | 8778,9 | 8970,4 | 9968,3 |

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## 2.8 Energy security impacts module

The energy security impacts module is included/supported in the Power system optimisation module described in the section 2.7 Optimisation of power sector operation (central system) for expansion planning. In the following the indicators used to assess the energy security impact that were used in our assessment are presented in short.

With power system optimisation model two energy security indicators are calculated, namely: Loss of Load Expectation (LOLE) and Expected Energy Not Served (ENS), whilst with REES-SLO model, import dependency indicator, Diversification of sources in electricity generation indicator and Present value of the costs is calculated and assessed. Furthermore, the newly developed Macroeconomy model, and its connection with REES-SLO model enables the assessment of shocks to the economy and provides the methodological framework for evaluating the resilience of national economy to unexpected economic circumstances.

### 2.8.1 Loss of Load Expectation

In our security of supply assessments, we use the indicator of the expected duration of the use coverage outage, LOLE - Loss of Load Expectation). **The LOLE indicator is calculated in Power system optimisation model**.

The LOLE indicator gives adequacy to the power sector and describes the likelihood that production capacity in the system (domestic production capacity considering imports from abroad) will not be able to cover overall use. It is calculated on the basis of hourly use and power plant reliability data and provides the expected number of hours per year when the total use in the system will not be powered. In Slovenia, the planning limit value used to ensure security of electricity supply is set to a maximum of 10 hours/year, which is in line with the recommendations of ENTSO-E (European Network of Transmission System Operators for Electricity). A significant influence on the LOLE indicator has an increase in electricity imports that replace production from domestic power plants, thereby increasing the power reserve in the power system and consequently reducing the LOLE indicator.

### 2.8.2 Expected Energy Not Served (ENS)

Expected Energy Not Served (EENS) or Expected Energy Unserved (EEU) represents an ENTSO-E metric which could be used to measure security of supply as well as to set a reliability standard in the electricity market. **The EENS indicator is calculated in Power system optimisation model**[6].

EENS means, in a given zone and in a given time period, the energy which is expected not to be supplied due to insufficient resources to meet the demand. In the context of this Methodology, Energy Not Served (ENS) refers to the simulated unserved energy, calculated for each hour of the simulation. The indicator represents the amount of electricity demand - measured in MWh – that is expected not to be met by generation in a given year. This combines both the likelihood and the potential size of any shortfall. The so-called 'Winter Energy Package' applies the EENS as the key metric for European resource adequacy assessments.

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[6] In Power system optimisation model it is reffered as ENS.

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### 2.8.3 Import dependency

**The import dependency indicator by use sector and by fuels is calculated for each scenario with the REES-SLO model**. Slovenia is 100% dependent on imports of petroleum products and depends almost 100% on imports of gaseous fuels. In 2008 dependence was highest in transport fuels, with a share of petroleum products in the transport sector of 98.2%. The total import dependency of Slovenia in 2008 was 55.3%. For the projections calculated with REES-SLO model we compare scenarios for the indicator of Slovenia's total import dependency by year and import dependency by use sector (industry and construction, transport, services and households) and energy products.

### 2.8.4 Diversification of sources in electricity generation

In accordance with the Energy Act, the **assessed scenarios with REES-SLO model pursue the objectives of the planned diversification of the use of natural resources and the reliable and quality supply of energy**. The most commonly used indicator of strategic reliability in the field of electricity is the so-called appropriate diversification of primary energy products used in the production or conversion into electricity. The basic indicator of appropriate diversification represents the share of different primary energy products in electricity production relative to gross end-energy use. An additional indicator is also often used, which shows the ratio of domestic resources vs. imported sources for electricity generation. Slovenia has a balanced structure of sources for electricity generation (coal, hydropower, nuclear energy) and open possibility of further diversification.

### 2.8.5 Resilience to unexpected economic circumstances

An important element of strategic reliability is also the sensitivity of projects, activities and the economy to significant changes in the price of imported energy or sensitivity to price pressures. General indicators of the impact of energy activities on the company's competitiveness are the cost of energy services or final energy prices for consumers.

**To assess the macroeconomic impacts of the changes in the economy the REES-SLO model has been connected with the Macroeconomy model**. In that manner, the impact of various policy measures and the shocks to the economy are assessed. In the context of the requirement to minimize the cost of energy production, it makes sense to monitor the indicator of the present value of energy costs (**Present value of the costs**). The indicator is in line and resonates with the economic efficiency of individual energy scenarios in energy supply. It is assumed that the most efficient energy scenario will be the one with the lowest present value of energy supply costs. This indicator was not used in the evaluation of individual projects but it was used in the evaluation of the overall scenarios. The requirement to minimize the impact of reducing added value in the event of an increase in energy/energy prices or suppliers relates to the market share of the price, while in the case of transfer payments (fees, taxes) we count on other effects, in particular the internalisation of external costs and market-steering effects, or the achievement of complementary objectives (employment, education).

# Abbreviations, figures and tables

## List of abbreviations

| | |
|---|---|
| ***ARSO*** | Slovenian Environment Agency |
| ***ASHP*** | Air-source heat pump |
| ***BAT*** | Best Available Technology |
| ***BEV*** | Battery Electric Vehicles |
| ***BHE*** | Borehole heat exchanger |
| ***BREF*** | BAT reference document |
| ***CAES*** | Compressed Air Energy Storage |
| ***CCS*** | Carbon capture and storage |
| ***CCU*** | Carbon capture and utilization |
| ***CES*** | Central Energy Supply |
| ***CHP*** | Combined heat and power |
| ***CNG*** | Compressed Natural Gas |
| ***DH*** | District Heating |
| ***DHC*** | District heating and cooling |
| ***EEA*** | European Environment Agency |
| ***EES*** | Electrical Energy System = Power system |
| ENS | Energy Not Served |
| ***EU*** | European Union |
| ***EU ETS*** | EU Emissions Trading System |
| ***EUE*** | End use of energy |
| ***EUL*** | Energy use loses |
| ***FE*** | Fugitive Emissions |
| ***GCHP*** | Ground-coupled heat pump |
| ***GDP*** | Gross Domestic Product |
| ***GEH*** | Statistical method by Geoffrey E. Havers |
| ***GEP*** | Geothermal parameters |
| ***GHG*** | Greenhouse Gas |
| ***GIS*** | Geographical Information Systems |
| ***GSHP*** | Ground-source heat pump |
| ***GWHP*** | Ground-water heat pump |
| ***HDV*** | Heavy Duty Vehicles |
| ***ICT*** | Information and Communication Technologies |
| ***IEA*** | International Energy Agency |
| ***IOT*** | Internet of Things |
| ***IPCC*** | Intergovernmental Panel on Climate Change |
| ***LCC*** | Life cycle costing |
| ***LDV*** | Light Duty Vehicles |
| ***LIFE*** | EU's funding instrument for the environment and climate action |
| ***LOLE*** | Loss of Load Expectation |
| ***LPG*** | Liquefied petroleum gas |
| ***LTS*** | Long Term Strategy |
| ***MESAP*** | Modular Energy System Analysis and Planning Environment |

| | |
|---|---|
| ***MFH*** | Multi Family House |
| ***NEC*** | National Emission reduction Commitments |
| ***NECP*** | National Energy and Climate Plan |
| ***NMVOC*** | Non-methane volatile organic compounds |
| ***NPP*** | Nuclear Power Plant |
| ***NPV*** | Net Present Value |
| ***NTC*** | Negative Temperature Coefficient Thermistor |
| ***ORC*** | Organic Rankine Cycle |
| ***PET SLO*** | PEnetration of Technologies for SLOvenia model |
| ***PHEV*** | Plug-in hybrid electric vehicle |
| ***pkm*** | Person kilometres |
| ***PM*** | Particulate Matter |
| ***PP*** | Power Plant |
| ***PRIMOS*** | PRometni Integralni MOdel Slovenije |
| ***PV*** | Photovoltaics |
| ***RCP*** | Representative Concentration Pathways |
| ***REES*** | Reference Energy and Emission System |
| ***REES-IND*** | Reference Energy and Emission System model for INDustry |
| ***REES-SLO*** | Reference Energy and Emission System model for SLOvenia |
| ***RES*** | Renewable Energy Sources |
| ***SFH*** | Single Family House |
| ***SGE*** | Shallow geothermal energy |
| ***SGEP*** | Shallow geothermal energy potential |
| ***sHPP*** | Small Hydro-electric Power Plant |
| ***SPP*** | Solar Power plant |
| ***tkm*** | Ton kilometres |
| ***TPP*** | Thermal Power Plant |
| ***TSP*** | Total Suspended Particles |
| ***UNFCCC*** | United Nations Framework Convention on Climate Change |
| ***WAM*** | With Additional Measures |
| ***WAMa*** | With Additional Measures - ambitious |
| ***WEM*** | With Existing Measures |
| ***WOM*** | Without Measures |
| ***WPP*** | Wind Power Plant |

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## List of figures

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